Fungi as food

Gramps: are you sure we can eat this one?

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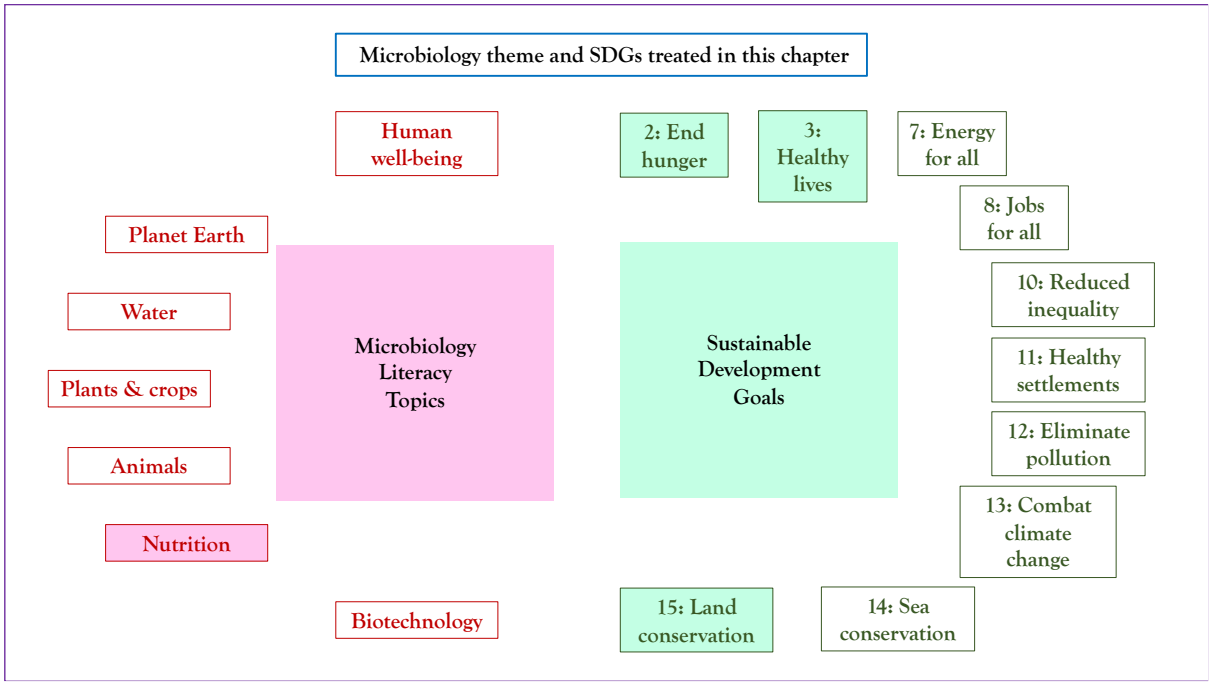
Storyline

The role of fungi as food, and in food production, is greatly undervalued. Mushrooms can be grown in the dark and on waste materials, while mycoprotein is promoted in huge vats with minimum input of energy, water and nutrients. Fungi play a key role in the production of bread, beer, wine and certain cheeses, and can promote growth of crops by supplying their roots with nutrients. Fungi can also prevent the loss of crops to insects and microbial pathogens, and prevent crops being outcompeted by weeds. Fungi, therefore, may be important to delivering Sustainable Development Goals (SDGs) centred around ending hunger, feeding people a healthy diet, and land conservation.

The Microbiology and Societal Context

The microbiology: fungi can play a huge role in nutrition by being edible themselves, as mushrooms and mycoprotein; aid in food production; and prevent the destruction of crops by insects and other microbes. *Sustainability issues:* mushroom and mycoprotein production have lower energy and water requirements than crops and meat; mycorrhizal fungi can negate the need for fertilisers that lead to eutrophication; and mycopesticides can replace chemical pesticides that are causing biodiversity loss.



Fungi as food: the Microbiology

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1. Cultivated mushrooms. Although fungi are microbes, not all fungi need a microscope to be visualized. When we talk about "mushrooms" we are referring to macrofungi, which are the fruiting bodies produced by fungi to disperse spores. Edible mushrooms are naturally high in vitamin D (the only dietary source of vitamin D for vegans!), low in calories, carbohydrates, calcium and sodium, and contain large numbers of vitamins and minerals. Commercial mushroom production has increased greater than 25-fold in the past 35 years, with button, oyster and Shiitake mushrooms accounting for 85% of worldwide consumption.

Fungiculture is increasing because mushrooms can be grown in the dark and on a wide variety of substrates, including waste products such as recycled paper and coffee grounds. Mushroom cultivation is low-cost and has low environmental impact, so it is being explored as a solution to poverty and malnutrition in less economically developed countries. On the other hand, peat-containing soils are mostly used for mushroom cultivation, which is unsustainable and harmful for peat bog preservation and restoration. Alternatives are currently being sought to enable upscaled fungiculture.

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2. Wild foraged mushrooms. There are an estimated 15,000 species of mushrooms to be found in the UK: in woods, on riverbanks and in meadows. Responsible foraging can be a fascinating and rewarding experience as many wild mushrooms are abundant and delicious, including oyster mushrooms, chicken of the woods, giant puffballs, porcinis and chanterelles. However, there are also many wild mushrooms that are poisonous – with apt names such as deadly webcap, destroying angel, death cap and funeral bell – that result in symptoms from hallucinations and abdominal pain to brain injury and death when ingested. Whilst foraging can contribute tasty morsels to the dinner table, no-one should ever consume a mushroom unless they are 100% sure what it is.

It is important to note that over-foraging is a conservation concern for certain species: some mushrooms are endangered and many woodland areas are now protected because of over-foraging and ecological damage done to the area. Illegal foragers face fines if they are caught.

3. ***Mycoprotein.*** Due to food shortages in the 1960s, a research program was established to look for sustainable sources of protein. Researchers screened 3,000 soils from across the world and, in a soil collected from a wheat field in Marlow, Buckinghamshire, they found *Fusarium venenatum*. Spores from this microfungus are fermented with glucose and other nutrients to produce a protein-rich fungal biomass called mycoprotein, now known as Quorn™ (https://www.quorn.co.uk/company). Quorn™ is high in protein and fibre and low in fat, cholesterol, sodium and sugar, so many people eat it as a meat substitute in an effort to reduce their carbon footprint. Research has shown than mycoprotein promotes the feeling of being full, which prevents over-eating leading to obesity. It helps control blood sugar levels by increasing sensitivity to insulin, and can reduce blood lipids. It may also promote gut health.

Mycoprotein is produced by fermentation. Starting from one gram of mycoprotein as an inoculum, 1,500 tonnes are produced in each fermentation cycle, making it a highly sustainable and environmentally-friendly food source. Mycoprotein is one example of a single cell protein; others are in development.

Greenhouse gas footprints are expressed as carbon dioxide equivalents (CO_2e). Mycoprotein has a footprint of ~1.14 CO_2e per kg, compared to 2.4 CO_2e per kg for chicken and 12-60 CO_2e per kg for beef. Furthermore, the water footprint of mycoprotein production is 2,000 kg per kg of protein, which is about half of chicken and one tenth of beef.

4. ***Fungi in food production.***

a. **Yeast in bread and alcohol.** Perhaps the earliest known use of fungi in food production is baking and brewing using the yeast *Saccharomyces cerevisiae*, which is first depicted in Egyptian hieroglyphs from 4,000 years ago. The importance of yeast comes from its ability to convert sugars into carbon dioxide and ethanol under both aerobic and anaerobic conditions, which is what causes bread dough to rise, and makes wine and beer alcoholic. In the UK, the alcohol industry alone contributes approximately 2.5% of total gross domestic product (GDP) to national income and it is estimated that in the US 3% of the workforce is employed in yeast-based production.

b. **Cheese production**. *Penicillium roqueforti* produces the blue veins in cheeses such as Roquefort, Stilton, and Gorgonzola, and *Penicillium camemberti* produces the rind on soft cheeses like Camembert and Brie, enhancing their flavour and aroma.

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c. **Fermented foods**. Many components of Asian cuisine are produced by fermentation using moulds: for example, wheat and soybean are fermented by *Aspergillus oryzae* or *Aspergillus sojae* into soy sauce, and rice is fermented by *Aspergillus oryzae* or *Saccharomyces cerevisiae* into sake.

d. **Dried meats.** *Penicillium salamii* colonises the surface of dry-cured meats, increasing their shelf-life by preventing spoilage by other microbes.

5. Food crop health and growth promotion.

a. **Mycorrhizal fungi.** Around 80% of plant species form interactions with mycorrhizal fungi in and around their roots, supplying them with carbon in return for nutrients such as nitrogen and phosphorus obtained by the fungi. These fungal interactions are important for food security as they enhance growth of important crops such as rice, corn, soybean and wheat, by increasing their resistance to drought and disease, decreasing the need for phosphorus and nitrogen fertilisers and alleviating stresses to the plant such as pollution and heavy metal contamination.

b. Mycopesticides. Soil fungi can also provide the solution to our pest problem, which is expected to worsen as global temperatures rise. At present, 40% of crops are lost to insects, pathogens and weeds, which therefore constitute a major contributor to food insecurity, and there is growing interest in fungi as pesticides, fungicides and herbicides. There are currently 171 licensed products that, between them, use 12 species of insect-killing fungi as the active ingredient to control 48 families of insect pests. Mycofungicides are commercially available that protect against powdery mildew, root rot disease and soilborne pathogens. With growing concerns over the impact of chemical interventions on water quality and pollinator diversity, these fungal species that naturally occur in soil and trigger outbreaks to control pest populations in nature could be our solution.

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Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture**. Mushrooms are nutritious and their cultivation is low-cost so can make a contribution to poverty and malnutrition. Mycoprotein is nutritious and, because it is produced by fermentation, it does not compete for farmland and is readily upscaled, so can also contribute to ending hunger. Moreover, production of mycoprotein has lower energy

requirements and is more sustainable than animal protein production from livestock farming and therefore can be upscaled to feed the global population with lesser environmental impact.

- **Goal 3. Ensure healthy lives and promote well-being for all at all ages.** Mycoprotein (and perhaps mushrooms and fungi in general) may have health benefits beyond nutrition. On the other hand, some mushrooms are poisonous and cause injury and death, if ingested.
- **Goal 13. Take urgent action to combat climate change.** The use of peat-containing soils for the production of cultivated mushrooms ultimately leads to the release of greenhouse gases from the carbon that has been locked up in peatlands and wetlands for geological time. Alternative substrates for mushroom cultivation must be found to reduce this source of greenhouse gas emissions and its contribution to global warming. On the other hand, food animal husbandry for meat production is a major source of greenhouse gas production, especially the production of meat from ruminants, and the cereal production associated with the feeding of such animals. The production of mycoprotein, and other single cell proteins, by fermentation has a much lower carbon footprint and hence is much more sustainable.
- **Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems.** The growing world population, and the socio-economics of food production, results in progressive loss of important natural habitats and ecosystems to create more farmland. The production of single cell protein by fermentation requires vanishingly small amounts of land that does not have to be farmland, so does not require the destruction of natural habitats. Agriculture presently relies on the extensive use of agrochemicals which pollute soils and receiving waters. Alternative farming practices and the use of biofertilisers and biopesticides, such as mycopesticides, can reduce biodiversity loss and the environmental impact of large-scale farming. Importantly, understanding mycorrhizal fungi communities in soils may help us to reverse soil degradation and increase soil productivity for sustainable crop growth.

Potential Implications for Decisions

1. ***Individual***

a. If an individual intends to eat the mushrooms they have foraged, they must be 100% sure they know the identity of the mushroom. There are many resources available for doing so: join a local mycology group, buy a recommended mushroom field guide and/or follow Facebook pages for mushroom spotters.

2. ***Community policies***

a. Health costs for treating illness caused by mushroom poisoning.

b. Damage to local woodlands, grasslands or conservation areas by foraging activities.

c. Depletion of fungal populations due to over-foraging.

3. ***National policies***

a. Destruction of peat bogs to supply peat-containing compost for mushroom production.

b. Unintended/unforeseen effects of mycopesticides; may cause damage to non-target and beneficial insects and microbes.

Pupil Participation

1. ***Classroom activity***

a. what fungi have you eaten before?

b. talk/visit from an experienced mushroom forager with photos/specimens.
c. grow own mushrooms in class with off-the-shelf kit.

2. ***Homework***
a. take photos of foods in your home kitchen that are fungi, or have been made using fungi.
b. accompany parent to the supermarket and photograph all foods that are fungi, or have been made using fungi.

3. ***Class excursion***
a. woodland trip to photograph mushrooms and then identify species online, with help of experienced forager or local mycology group.

The Evidence Base, Further Reading and Teaching Aids

Videos
https://www.youtube.com/watch?v=IbLYOcJi5Jo
https://www.youtube.com/watch?v=XI5frPV58tY

Field guides for mushroom identification:
Mushrooms: A comprehensive guide to mushroom identification – by Roger Phillips
Edible Mushrooms: A Forager's Guide to the Wild Fungi of Britain and Europe – by Geoff Dann
River Cottage Handbook no1 Mushrooms – by John Wright
Collins Complete guide to British Mushrooms and Toadstools – by Paul Sterry & Barry Hughes
Mushrooms (Collins Gem) – by Patrick Harding & Alan Outen

Facebook pages for mushroom identification:
Mushroom Spotters UK
UK Mushroom hunters

Local mycology groups:
https://www.britmycolsoc.org.uk/field_mycology/recording-network/groups

Further reading:
María Elena Valverde, Talía Hernández-Pérez and Octavio Paredes-López. Edible Mushrooms: Improving Human Health and Promoting Quality Life. *Hindawi* (2015). https://doi.org/10.1155/2015/376387

S. Bhuvaneswari ManivelG. Subashini Rajkumar. Mycopesticides: Fungal Based Pesticides for Sustainable Agriculture. *Fungi and their Role in Sustainable Development: Current Perspectives* (2018).

Min Chen, Miguel Arato, Lorenzo Borghi, Eva Nouri and Didier Reinhardt. Beneficial Services of Arbuscular Mycorrhizal Fungi – From Ecology to Application. *Frontiers in Plant Pathology* (2018). https://doi.org/10.3389/fpls.2018.01270

Glossary

Biofertiliser = a substance that contains live microorganisms that can supply nutrients to plants, negating the application of chemical fertilisers.
Biopesticide = a substance that contains live microorganisms that protect crops from pests such as insects and microbial pathogens.
Macrofungi = fungi that are visible to the human eye e.g. mushrooms
Microfungi = fungi that are not visible to the human eye and can only be viewed under the microscope.
Mycofungicide = a substance containing fungi that protects crops from fungal pathogens.
Mycopesticide = a substance containing fungi that protect crops from pests such as insects and microbial pathogens.
Mycoprotein = protein-rich food source produced from the fermentation of fungal spores.
Mycorrhizal fungi = fungi that form symbiotic relationships with plant and tree roots; supplying them with nutrients from the soil in exchange for carbon.