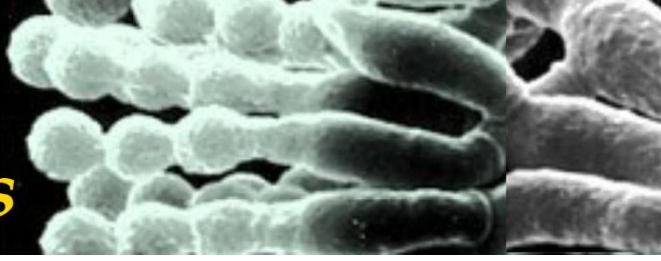
MiSAC matters
MICROBIOLOGY IN SCHOOLS ADVISORY COMMITTEE
50th Anniversary Articles



Superstore - super fungi! How much do you owe the fungi for your shopping basket?

David Moore

We all have different attitudes to fungi, but do you know just how much, every hour of every day, we all depend on fungi and fungal products? Or how much fungi contribute to our everyday retail experience? Let's take a walk around the nearest superstore and look at the fungal contribution to the goods on sale.

Mushrooms. Mushrooms are a high-quality food source with protein typically 20-30% of dry matter, and containing all the amino acids that are essential to human nutrition, low-fat content, and useful B vitamin content. Fungi are easily digested and their cell walls provide a good source of dietary fibre. Most important of all they have no cholesterol. European mushroom farms cultivate *Agaricus bisporus*. Oyster and Paddy straw mushrooms are cultivated in Asia; though in Japan and China *Lentinula* (shiitake in Japanese or shiangu in Chinese) is a major crop.

Fresh meat and dairy products. Our farm animals are kept alive by the fungi in their digestive systems to cope with otherwise indigestible fibres in grass. The gut of ruminants (like cattle) contains large chambers that form a fermentation vessel where the microbes grow. The fungi concerned are known as 'obligately anaerobic chytrids'; they digest lignin and carbohydrate and pass some nutrients on to methanogenic bacteria. The two work together, carrying out a more efficient fermentation process, generating a larger microbial community, and greater benefit to the host animal when it digests the microbes.

Bread. Leavened bread is a product of the fermentation of sugars from cereal grains by the yeast *Saccharomyces cerevisiae*. This is known, not surprisingly, as Baker's yeast in this industry, although in the old days it was supplied to bakers by brewers. The yeast uses the same chemistry of ethanol fermentation for both industries: $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$. However, for the brewer the key product is ethanol; for the baker the key product is the carbon dioxide. Bread structure depends on the gluey properties of the wheat gluten protein. Carbon dioxide gas is trapped into bubbles by the gluten, and the bubbly structure of the dough is turned into the open structure of bread when cooked. For hundreds of bread recipes see: http://www.cookitsimply.com/category-0020-0e1.html

Beers and Ales. These are products of the fermentation of sugars from cereal grains by the yeast called *Saccharomyces cerevisiae*. All ales, beers and lagers are made from malted barley mashed into hot water and boiled with hops to add bitter flavours to the beer. The yeasts used for making ales tend to form froth and grow on the top of the mix. Lager yeasts ferment at the bottom of the tank and belong to the closely-related species *Saccharomyces carlsbergensis*. (See: http://www.howtobrew.com/).

Fuel alcohol. Ethanol is also used as a chemical feedstock and as an automotive fuel when up to 10% ethanol by volume is mixed with petrol. Yeast fermentation of agricultural wastes is most often used. Together, the USA and Brazil produce 85% of the world's fuel ethanol. Most of the US ethanol is produced from maize and other cereals, while Brazil uses sugar cane. The US produces most fuel ethanol; over 100 billion litres were produced worldwide in 2017, of which 60 billion litres was produced in the US, 27 billion in Brazil and 5.3 billion in the EU (https://www.afdc.energy.gov/data/).

Wines. *Vitis vinifera* grape juice is obtained by crushing grapes; the grape juice is referred to as

must, which is fermented with an elliptically-shaped yeast called *Saccharomyces ellipsoideus*. This is usually added as a starter yeast culture made up in grape juice. After the yeast fermentation, quality wines take one to four years to age in wooden casks. For some wines a bacterial fermentation is encouraged during aging to mellow the taste by reducing acidity. For sparkling wines, sugar, and a special strain of yeast that forms granular sediment, are added when the wine is bottled and a secondary fermentation in the bottle produces carbon dioxide bubbles (source: http://www.oiv.int/en/).

Marmite. Brewing beers produces a vast amount of live yeast as a 'waste' product and these brewery wastes are converted into flavourings, diet supplements and 'yeast extract' products with brand names like Marmite, Meridian Yeast Extract and Australian Vegemite, Swiss Cenovis, and the German Vitam-R. In the first stage of Marmite production, the brewer's yeast is broken down to proteins and soluble amino acids; this mixture is filtered, secret flavourings (in a vegetable juice concentrate), vitamins and spice extracts are added, and the product is ready for packaging (https://www.marmite.co.uk/).

Quorn. Mycoprotein™ is the name for a food product made from a strain of the filamentous fungus *Fusarium venenatum*. The fungus is grown on food-grade glucose as the carbon source in a 45 m tall airlift fermenter. Mycoprotein typically contains 44% protein, 18% dietary fibre and only 13% fat (the values for beef are 68%, 0% and 30% respectively), and raw mycoprotein contains no cholesterol. The sole use for mycoprotein currently is as the primary ingredient of the Quorn™ range of 'meat-alternative' products. See (https://www.quorn.com/).

Cheese. Cheese is a solid or semisolid protein food product manufactured from milk. Before the advent of modern methods of refrigeration, cheese manufacture was the only method of preserving milk. Basic cheese making is a bacterial fermentation, but there are two important processes to which filamentous fungi contribute. These are the provision of enzymes (80% from moulds like *Aspergillus* spp. and *Mucor miehei*) which, at the start, coagulate (curdle) the proteins in milk, forming solid curds (from which the cheese is made) and liquid whey; and fungal growth is also responsible for the process known as mould-ripening. This mould ripening is a traditional method of flavouring cheese that produces blue cheeses (using *Penicillium roqueforti*), and Camembert and Brie cream cheeses (ripened by *Penicillium camemberti*) (https://cheese.com/).

Salami manufacture. *Penicillium nalgiovense* is the most widely used filamentous fungus in the production of cured and fermented meat products. Chopped meat (including beef, goat, horse, lamb, pork, poultry, and/or venison) is mixed with minced animal fat, cereals, herbs, spices; this mixture gives the salami sausage its typical marbled appearance when cut. Salt is added and the mixture ferments for a day before being stuffed into a casing, covered with a suspension of the *Penicillium nalgiovense* starter culture, and finally hung to cure. As the fungus grows over the sausage and into the meat it imparts flavour and protects against spoilage by other undesirable species of yeasts, moulds and bacteria.

Fizzy drinks. Apart from alcohol (ethanol), the single most important pure chemical produced by fermentation is citric acid (global production is about 1,600,000 tonnes annually). This is a weak 6-carbon organic acid that is a naturally occurring component of metabolism in almost all living things. The structure of the molecule confers a variety of properties that make citric acid useful in foods, effervescent soft drinks, and pharmaceuticals as a pH buffer, acidifier, preservative and/or metal ion chelator. The standard fermentation production method uses *Aspergillus niger* on a medium containing 15% sugars. Under optimal conditions, fermentation is complete in 5 to 10 days (https://ihsmarkit.com/products/citric-acid-chemical-economics-handbook.html).

Fruit juices. Fungal enzymes are used extensively in production of non-effervescent fruit juices to maximise the yield of extracted juice. For example, processing apples utilises 'macerating enzymes',

that is, fungal enzymes like pectinases, cellulases and hemicellulases, which separate the cells of the tissue and weaken the cell walls. This increases the yield of juice collected and improves release of antioxidants and vitamins. In later stages, enzymes are used to remove any precipitates formed by insoluble fruit residue and clarify the juice before packaging.

Soy sauce, tempeh and other food products. Fungi are used for processing several food products that enjoy large markets in Asia, and traditional oriental cooks have applied a variety of fermentation techniques to the seeds of soya, rice and other crop plants in ways like the fermentation techniques that traditional occidental cooks have applied to dairy products and meat of various animals. Fermentation of soy beans with filamentous fungi (particularly *Aspergillus*, *Actinomucor*, *Mucor*, or *Rhizopus* spp.) is the basis for production of a range of foods, including sufu (fermented tofu), soy nuggets, tempeh, miso and ang-kak (red rice). Bacterial fermentation is used to produce natto and soy yoghurt. Non-fermented soyfoods include soymilk, tofu, soy sprouts, yuba (soymilk film), okara (soy pulp), vegetable soybeans, soynuts and toasted soy flour.

Chocolate and coffee. All chocolate products are derived from cacao seeds formed in large pods on the trunks of the evergreen cacao tree (*Theobroma cacao*). Each pod contains about 40 seeds (the cocoa 'beans', though they are not true beans) embedded in a fleshy pulp. Pod contents are scooped out and pulp and seeds piled in heaps for several days, during which they undergo a natural microbial fermentation by a succession of yeasts and bacteria. This liquefies the pulp and imparts the flavour of chocolate to the cocoa seeds that are left behind. Unfermented cacao seeds do not have any chocolate flavour. Coffee undergoes a similar fermentation, and for similar reasons. Several species of the bushy tree *Coffea* produce cherry-like fruits that contain two seeds (the coffee 'beans'). Harvested fruits have most of the berry flesh removed in water, then the coffee seeds ('beans') are fermented in large water containers to dissolve away a parchment-like film of tissue that surrounds them. When complete, fermented coffee beans are washed, then sun-dried, making the 'pergamino coffee' that is exported. Most of the flavour of coffee forms when the 'beans' are roasted; but cultivar, geographical origin and the fermentation all contribute to the more than 850-or-so aroma and flavour compounds so far found in coffee.

In the pharmacy. Fungus-produced penicillin is still an important antibiotic, but most antibiotics that we use today originate from bacteria (grown in large fermenters). Fungi produce some other crucial pharmaceuticals, though: for example, the fungal product called cyclosporine, which suppresses the immune response in transplant patients to avoid organ rejection. Mevinolin is a compound produced by the fungus *Aspergillus terreus* which is the basis of the statins. These are used to reduce cholesterol levels; high cholesterol is a risk factor in cardiovascular disease, stroke and several other widespread illnesses. Since their introduction in the late 1980s, statins have become the most widely prescribed cholesterol lowering drugs in the world. Fungi also produce compounds known as ergot alkaloids, which were the first antimigraine drugs available. Although these can be synthesised, fermentation remains the most cost-effective production method. Steroid compounds are among the most widely marketed products of the pharmaceutical industry and most of the steroids in clinical use today are modified by fungi and/or fungal enzymes during manufacture. Using fungi and their enzymes enables compounds to be made that would otherwise be very difficult, impossible, or just too expensive to produce by direct chemical synthesis. Manufactured steroids are used for many 'over-the-counter' remedies as well as ethical (prescription-only) therapies. Common uses include anti-inflammatory, immune-suppressive, diuretic, anabolic, contra-ceptives and progesterone analogues. Manufactured steroids are also used to treat some cancers, osteoporosis and adrenal insufficiencies (the adrenal glands produce natural steroid hormones), for avoidance of coronary heart disease, as antifungal or anti-obesity agents, and some steroids can be used to prevent and treat infection by HIV.

Clothing: enzymes for fabric conditioning and processing. Despite the successful emergence of

synthetic fibres such as nylon and polyester, a great many of our fabrics are still made from the natural fibres cotton (cellulose), wool and silk (both protein), all of which can be processed in various ways with natural enzymes. The fabric processing with which we are most familiar results from the inclusion of fungal enzymes in detergents and associated fabric conditioners used for clothes washing. Some of these enzymes are derived from bacterial sources, but many are fungal enzymes. Enzymes are also used during manufacture of textile products to improve the properties of the fabrics. Fungal cellulase enzymes remove loose fibres from cotton fabrics more efficiently and more gently than mechanical methods of finishing. Many traditional finishing processes in the wool industry require chemicals that cause pollution. Fungal proteolytic enzyme treatments achieve a variety of finishing effects for woollen products with minimal environmental impact.

More information

- **Exploiting fungi for food:** http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Ch11_00.htm
- **Fungal biotechnology:** http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Ch17_00.htm
- **Soy sauce and other fermented food products:** http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Ch17_25.htm
- ***World of Fungi:*** http://www.davidmoore.org.uk/index.htm

AUTHOR PROFILE

Dr David Moore was formerly Reader in Genetics in the Faculty of Life Sciences at Manchester University. His research interests were in fungal physiology and mutant isolation and linkage mapping in *Coprinopsis cinerea*. David has held a number of senior positions in the British Mycological Society including that of President and was creator and webmaster of its web site. He was instrumental in establishing the society's outreach and education work in schools, science fairs and RHS shows for which he has received the society's awards. David is the author of a number of books on mycology.