Coffee

Mom: coffee looks mucky and smells strong, why are you always drinking it?

Manual coffee berry pulping machine from Peru.
The beans in the basket have been depulped already. (credit: C Schwab)

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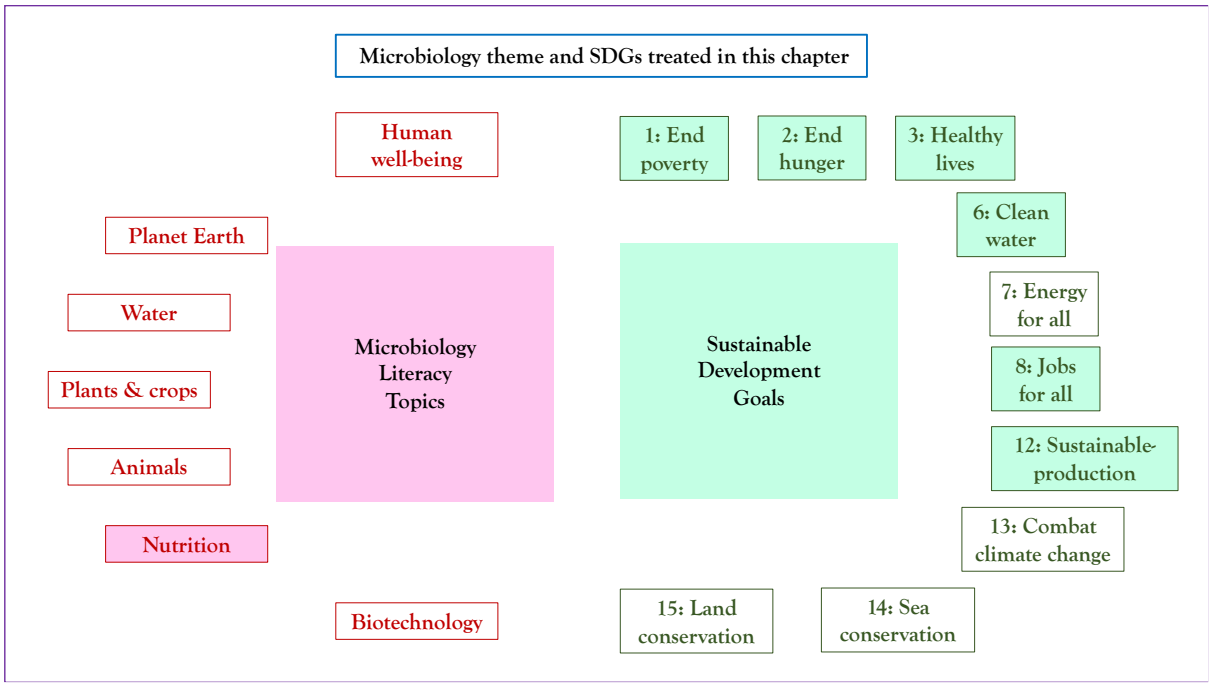
Storyline

A coffee in the morning. A coffee after a meal. A coffee with friends. Coffee and cake with the grandma.....Since the first evidence of coffee being drunk in the early 16th century in Yemen, coffee made its way worldwide. In Europe, the coffee trade started in the early 1600s; in the beginning, coffee was often consumed in specialized coffee houses. Coffee is considered an appetite suppressant, and is drunk to keep awake and to support digestion. The preference for special coffee brews (strong or mild, small or big volume, warm or cold, with or without milk, cream or sugar), and preferred drinking times and locations (at home, in a bar, in a coffee house,...) differ among regions and cultures. Nevertheless, there is a common view that coffee is an essential part of a high quality lifestyle. The Scandinavian countries are the biggest coffee drinkers if calculated per inhabitant (possibly because of the dark winters?). In any case, microbes play key roles in the production of coffee.

The Microbiological and Societal Context

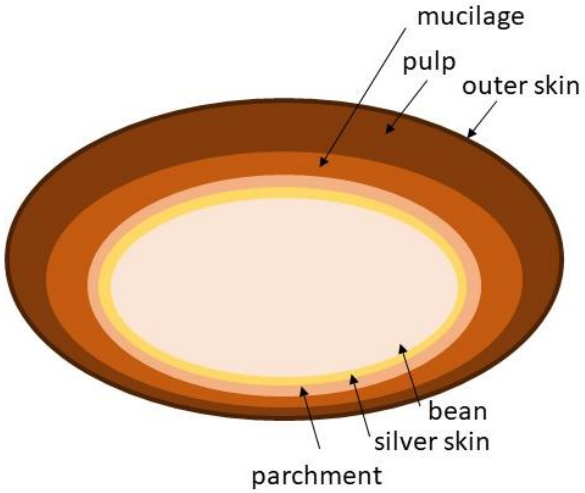
The microbiology: microbes in coffee fermentation; natural fermentation; starter cultures, unique coffee fermentation processes; fermentation to produce value-added compounds from nutrient rich waste streams; microbial ecology; microbial biotechnology. *Sustainability issues:* poverty and employment; water and energy, sustainable production and consumption



Coffee: the Microbiology

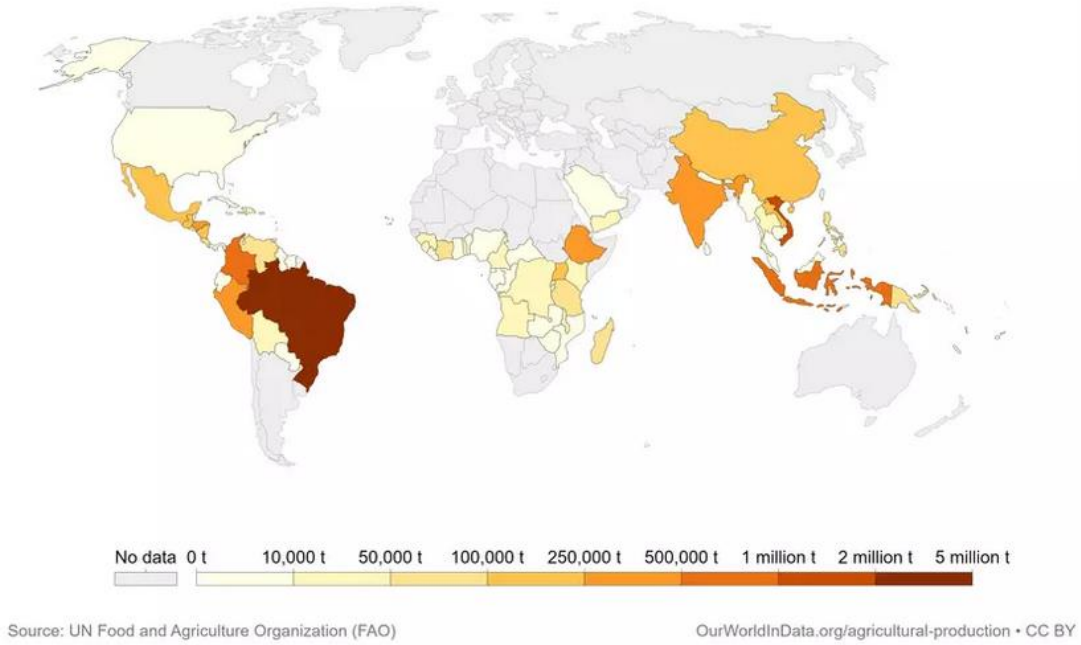
Coffee plant carrying berries. (By Jmhullot - http://www.fotopedia.com/items/jmhullot-ohX2WO1-lQc, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=7947317)

1. ***What is coffee?*** Coffee plants produce berries (or cherries), which are called green coffee beans after initial processing (see section 2.), even though they are not really beans. A coffee berry consists of the one or two beans (endosperm) surrounded by a silver skin (spermoderm), parchment (endocarb) and mucilage, which are embedded in pulp (mesocarp) The entire fruit is covered by an outer skin layer (pericarp, exocarp). The coffee plant needs three years to produce its first berries!



Schematic drawing of a cut coffee bean.

A coffee berry contains carbohydrates (around 50%), lipids (around 13%), proteins and amino acids (around 10%), caffeine (1-3%) and numerous smaller compounds. Worldwide, the most important economic varieties of the coffea plants are *Coffea arabica* (Arabica, around 60-80%) and *Coffea canephora* (Robusta, around 20-40%), but there are more than 100 other varieties. Originally, the coffee plant grew in tropical Asia, and in tropical Southern Africa. Coffee plants grow well at higher altitude and under temperate or tropical conditions characterized by a lot of water and sunshine, and without frost. Currently, the main coffee growing zone is around the equator. The countries producing the most coffee are Brazil, Indonesia, Vietnam, Colombia and India.



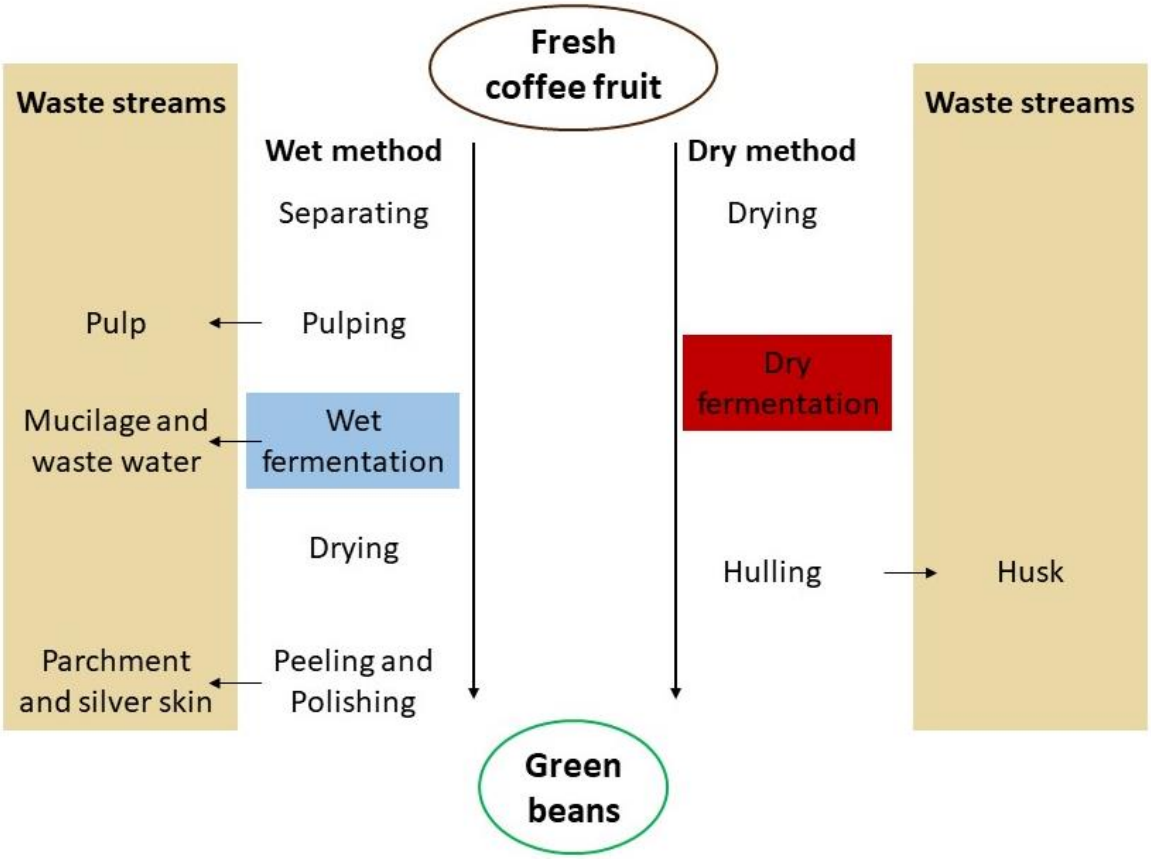
Countries that produce the major share of coffee worldwide.

2. ***The coffee production process.*** When ripe, coffee berries are either picked by hand or with the help of machines. Traditionally, the process then continues either using the 'Wet', or the 'Dry' method.

Wet method: A mixture of ripe and unripe coffee berries are suspended in water, in which the good and ripe berries sink to the bottom, separating them from the unripe berries. These are then collected and the outer skin and pulp is removed mechanically. The mucilage is then microbially fermented in water-filled fermentation tanks for up to 2 days (see section 3). The mucilage remains are then removed by additional washing. Finally, the hulls are removed, and the green beans are dried.

Dry method: In the dry process, the both ripe and unripe harvested berries are dried in the sun on the ground. A microbial fermentation also takes place during the drying process, which lasts 3-4 weeks. Afterwards, the outer parts of the coffee fruit are removed mechanically.

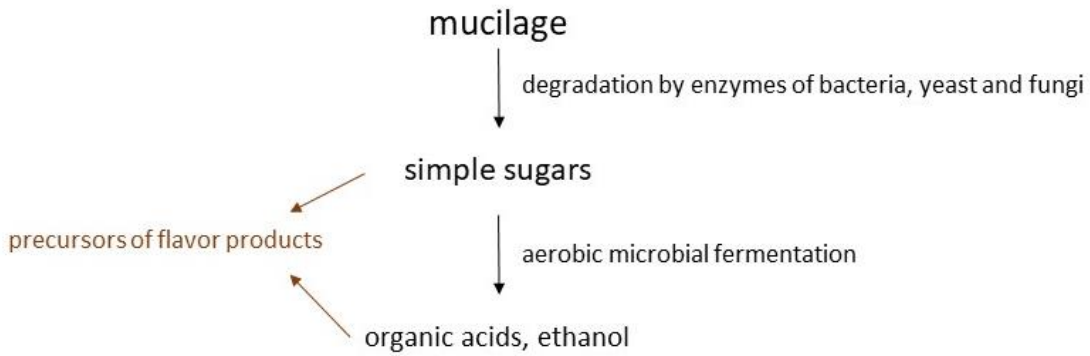
After both processes, the dried green beans are ready for storage, transport from the farm to the production facility, and roasting, as the water content has been reduced from around 65 to 10%. Spoilage by growth of microorganisms is now less likely. In general, coffee beans from the *wet process* are considered of higher quality and with more aroma.



Main steps of the coffee process from fresh coffee fruit to grean beans that can be used for roasting. The semidry method, a variation of the wet method, involves removal of the mucilage through mechanical processing.

3. ***What do microbes do to coffee berries?*** The mucilage layer is rich in the polysaccharides pectin, cellulose and starch. If not removed, the drying time becomes longer, and there is the danger of mould growth, and thus microbial spoilage of the coffee fruit. Microbes are therefore used to remove this mucilage layer by fermentation. During fermentation, microbes break down the polysaccharides to gain energy, producing smaller molecules that contribute to aroma and flavor.

The coffee bean fermentation is very complex and still not 100% understood, but it involves microbes from the environment and enzymes produced by the coffee bean itself, which together lead to the degradation and utilization of the mucilage. The main microorganisms involved in coffee fruit fermentation differ with region and season. The main players are bacteria (e.g. *Lactobacillaceae, Bacillaceae. Enterobacteriaceae*), yeast (*Pichia*, *Debaryomyces*, *Sacharomyces*, *Candida*, *Kloeckera* spp.), and filamentous fungi (*Penicillium*, *Aspergillus* and *Fusarium* spp.). In the wet process fermentation, filamentous fungi only occur infrequently, and bacteria and yeast are dominant, while in a dry fermentation, the microbiota is more diverse. The numbers that were reported differed widely between coffee cherries from different origin and different studies, with cell counts of bacteria ranging from 10.000 to 10 Mio, and of yeast between 10.000 and 100 Mio per gram.



The microorganisms fermenting coffee fruits provide several beneficial functions for the microbial community, and for coffee quality. Yeasts degrade the pectin mucilage and ferment sugars to alcohol. *Bacillus* spp. might contribute to pectin degradation, while lactic acid bacteria ferment the released sugars to organic acids, including lactic acid, which lowers the pH, and might produce additional antifungal compounds. Even if the exact mechanisms are not known, it is generally agreed that the metabolites produced by microbes during fermentation are beneficial for coffee quality, even after roasting.

To date, coffee bean fermentation is still a natural fermentation that relies on microorganisms provided by the environment, the equipment used for the process, and from the surface of the coffee cherry itself. With so many variables, the fermentation process is difficult to control, so studies have been carried out to investigate the use of defined starter cultures, similar to those used in the dairy industry, for example in the production of yoghurt or cheese, or in beer brewing. For coffee, this has not been entirely successful, and the tested starter cultures did not produce a fermented bean as good as the wild fermentation.

4. ***Something special: civet coffee.*** One type of coffee is fermented in a completely different and unique way: It is called civet coffee, and it originates from South-East Asia. A common variety is Kopi Luwak from Indonesia with a very smooth profile. Coffee cherries are fed to Asian palm civets, and are fermented by the gut microbiota during passage through the gastrointestinal tract of the animal. Similar to wet and dry fermentations, intestinal microbes and their enzymes break down carbohydrates and proteins surrounding the coffee bean. The civet serves as a living fermenter!

The production of civet coffee is under ethical debate, as the animals are kept on big farms in industrial settings. One alternative currently being explored is a biotechnological approach using in vitro fermentation systems to cultivate the intestinal microbiota of civets in bioreactors.

5. ***Can we use the waste products?*** The waste water produced during coffee bean fermentation is still rich in fermentable sugars. For example, the water that is removed after the wet fermentation contains the mucilage, and additional side products of the wet method are pulp and parchment. The main waste product of the dry method is husk. These byproducts are rich in organic components (e.g., proteins, sugars), and phenolic compounds which could be harmful to the environment if simply discarded. Therefore, researchers have investigated the possibility to make use of these waste streams. For example, pulp, mucilage and husk all contain the polysaccharide cellulose, while parchment has a high lignin content. With some optimization, these byproducts could be used to produce biogas or bioethanol.

6. ***The coffee value chain.*** The coffee value chain includes all the processes from cultivation and processing, to roasting and packaging, sales, and finally consumption. For a major producing country, coffee is a significant income source. An estimated 100 Mio families live on the income generated along the coffee value chain (farmers, traders, processors, roasters, distributors, packagers, marketers, baristas), but also including waste disposal, reuse and recycling. Although coffee is very popular worldwide, current trade mechanisms might not allow coffee farmers to benefit proportionally from this coffee popularity. For a more sustainable coffee production, maybe coffee farmers need to become more equal partners in the coffee industry?

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 1. End poverty**. An estimated 10-30 million people grow coffee for an income providing an income for many more, often in developing countries and often as small holders. The income of these farmers is highly unpredictable and varies with the market situation and the success of the harvest, which itself depends on climatic conditions.
- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.** Coffee plantations need land, the coffee process needs water, so consume agricultural resources that could be used for other purposes, like basic food production.
- **Goal 3. Ensure healthy lives and promote well-being for all ages.** The fulfillment of Goals 1 and 2 will support Goal 3. Moreover, coffee is considered to have health beneficial effects.
- **Goal 6. Sustainable water use. T**he coffee process, especially if the wet process is used, needs a lot of water. At the same time, wastewater is produced by the process, which needs to be processed before further usage.
- **Goal 8. Productive employment.** Coffee plant farming provides work to a significant number of people in low income countries, as does berry fermentation. Coffee roasting and production of the final product involves other industries. The manufacture of coffee capsules and instant coffee is yet another industry, as is the production of all of the various household machines used to convert what is bought into a cup of coffee. The coffee value chain thus creates and maintains significant productive employment.
- **Goal 12. Sustainable consumption and production.** Considering the resource-intense production process, the wastage of coffee beans and waste products should be avoided

Pupil Participation

1. ***Class discussions***
    a. how might the use of microbes contribute to a more reliable process in coffee bean fermentation?

2. ***Pupil stakeholder awareness***
    a. Coffee production is associated with significant footprints: agricultural resource commitment, freshwater needs, polluting waste streams, etc. On the other hand, it provides substantial employment and thus contributes to poverty reduction. Coffee production thus has positive and negative consequences for the SDGs. How might the negative consequences be minimized? How might the positive ones be optimised?
    b. Should we try and drink more or less coffee?

c. Do we need to grow coffee on a tree? New developments in cellular agriculture suggest to grow coffee beans in a plastic dish. What does that imply for farmers, the environment, and waste?
d. What happens if we use coffee capsules? Compare the resources needed, and waste produced if we drink filter coffee or coffee made from capsules.

The Evidence Base, Further Reading and Teaching Aids

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