

Fermentation of Coffee – Control of Operation

1. Introduction:

Wet processing of coffee often includes a fermentation step, cocoa always does and tea processing has a step that is sometimes called 'fermentation'. In food production there are many fermentations that confer nutritional, taste, stability or all of these benefits on raw materials. Sauerkraut, yoghurt, salami, tempe, uji, soya sauce, beer, and cheese are a few examples of scores of food fermentations known around the world.

Coffee fermentation, as we will see, is conducted for rather different reasons. The term 'fermentation' represents microbial growth as it occurs on any suitable substrate. In fact, in the early days of microbiology, the organisms that grew to spoil food were originally called 'ferments', rather than 'microorganisms', hence their growth was termed 'fermentation'.

A second, narrower sense of 'fermentation' is often used in microbiology, which we will not use in this discussion: microbial activity in the absence, or near absence, of oxygen. However, it is worth remembering that vigorous microbial metabolism often depletes oxygen (and so augments CO₂) thus oxygen limitation is usually an important aspect of food fermentations. It is an important factor in the selection of a fermentation community from the initial community of microorganisms. Bacteriologists also speak of fermentative organisms - microbes that do not require oxygen for respiration and oxidative species that do require oxygen for growth. In referring to organisms, we will use these bacteriological terms.

The so-called fermentation of tea raises an important aspect of some food fermentations. The changes wrought in tea by 'cutting, tearing, curling' (CTC), followed by aeration are produced by plant enzymes, not microbial activity. There is often a potential ambiguity in the roles of microbial and plant metabolism in processing systems since often both kinds of organisms are simultaneously active at some time during the process. Cocoa fermentation is required for flavour development although it also aids separation of seed from fruit tissue. Coffee fermentation, though it may have an impact on flavour development, is not required for flavour development and is conducted essentially to aid a similar separation of tissues.

Microorganisms occur naturally on and in the coffee fruit in increasingly large numbers as the fruit matures. The seeds themselves become active with maturity and a proportion of seeds will have undergone the early changes associated with germination by the stage of full ripeness. The fruit itself has no capacity to store, unlike apples and oranges, for example. Resident micro-organisms become active soon after harvest and signs of (unintended) fermentation can be measured soon after harvest. The object of our discussion here is principally the scheduled fermentation used to degrade the mucilaginous mesocarp tissue of the fruit.

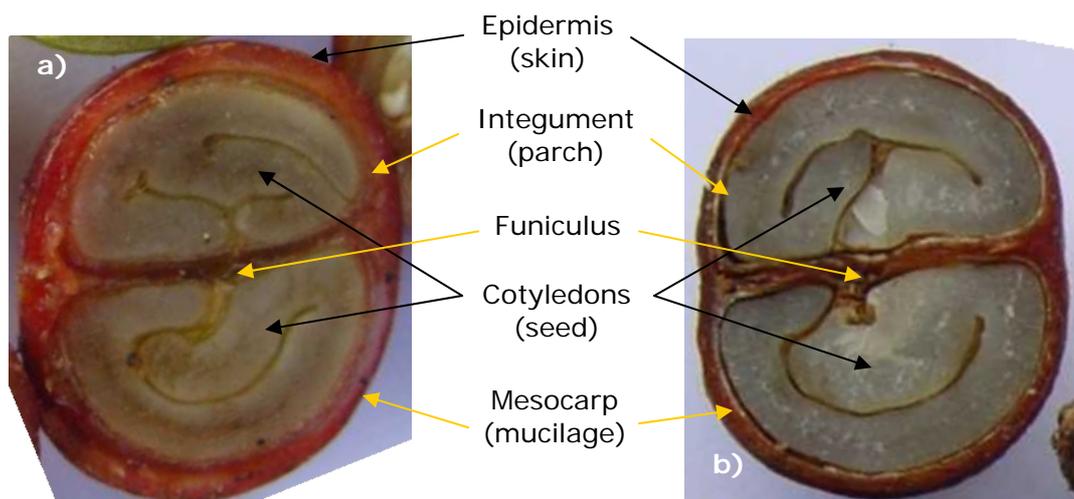


2. Structure and Composition of the Coffee Fruit:

The product of coffee are the seeds which are produced in small cherry-like fruits, normally in pairs. Of particular significance in understanding coffee processing are the three tissues of the fruit (Fig. 1): the epidermis (or skin); the mesocarp (or mucilage) and the inner integument (or parch).

The epidermis is typical of plants, comprising a layer of small cells, including stomata, their cell walls impregnated with suberin, a water impermeable wax. Beneath this is the mesocarp which consists of many layers of parenchymatous cells - undifferentiated thin walled cells and which, in the ripe fruit, are large with large vacuoles. The inner integument, which is tightly addressed to the seeds, is a very tough and relatively inelastic layer no more than two or three cells thick but comprising cells with considerable secondary thickening, i.e. it is essentially woody. Xylem tissue, presumably once connected to the funiculus (the tissue that connects the seed to its nutritional supply during development), can be easily seen in the integument by direct observation, running parallel to the surface of the tissue.

Fig. 1 - Transverse section of ripe fruit of a) *Coffea arabica* (arabica) and, b) *Coffea canephora* (robusta)



Before ripeness, the skin, mesocarp and parch form a tough and tightly addressed covering to the seeds which are relatively soft at this stage. Attempts to remove the seeds at this point will invariably break the seeds. When ripeness is reached, the mesocarp becomes soft (hence the term mucilage), and the seeds relatively hard. If mechanical shear is applied now, the mesocarp splits to produce one fraction of skins with some mucilage and a second fraction of seeds tightly covered in their integument (parch), which is covered in a fairly thick layer of mucilage. It is this second fraction that is fermented to enable removal of the mucilage from the seeds.

It can be seen in Figure 1 that the mesocarp of robusta fruit is thinner than that of arabica. It is, however, tougher and more difficult to remove from the parch. The mesocarp adhering to the parch is chemically quite different to that adhering to the skin. It lacks the characteristic anti-nutritional compounds such as tannins, free phenolics, caffeine and other alkaloids that make skins refractile even in

composting. A tonne of ripe arabica cherry yields about 120kg of mucilage adhering to the beans. About half of the 17kg of the dry mass of this mucilage is sugars or some 8.5kg of sugars. This is the source of fermentable carbohydrate for the coffee fermentation. There are also minerals, particularly Ca, K and P, and amino acids present.

Pectic substances amount to about 35% of the dry mass of the bean-associated mucilage. They comprise essentially polygalacturonic acid chains (covalent bonds typical of all polysaccharides) that are cross-linked, via Ca^{+2} ions through the carboxylic groups of the uronic acids. As will be discussed below, the ester part of the carboxylic group and the glycosidic bonds of the chains are susceptible to attack from enzymes.

3. Wet Processing vs. Dry Processing:

Coffee must be dried in order to stabilise it and preserve quality. Wet processing refers to various methods where the seeds are mechanically separated from the skin of the fresh fruit (pulping) before drying and may or may not include a fermentation step. Dry processing refers to methods where the fruit is either dried directly or is disrupted, but the seeds not separated from the fruit tissues, then immediately dried. The decision as to which method to employ is based on economic considerations. Washed coffee commands a higher price, but is more expensive to produce. A large proportion of arabica coffee is processed by the 'wet method' and a high proportion of this has a fermentation step in it. The market for washed robusta is limited, and the premium offered above dry processed robusta is small. Therefore, only a small proportion of robusta coffee is processed by the wet method, the bulk of this in India.

Capital costs for wet processing are high. Power, provided by mains electricity, petroleum powered generator or direct drive arrangements is required for even moderate sized operations. A good water source and fairly well-designed plumbing is also required. A facility to house equipment and various sealed channels and tanks are also necessary. The equipment comprises a pulper as a minimum, and typically includes a hopper, siphon tank, post pulping screen, washer or washing channels and skin-drying screens.

Fig. 2 - Some of the equipment and facilities required for wet processing: a) One of two disc pulpers, on a large estate, b) Siphon tanks, aqua-washers, soaking tanks, on a large estate, c) Smallholder pulper, d) Smallholder washing channels and table dryer



Operational costs are also higher for wet processing. Harvesting is particularly expensive because it requires the very labour-intensive selective harvesting system - only ripe cherries can be pulped. This is beginning to change due to new equipment that can accept (but not pulp) immature cherries. Further costs accrue because cherries affected by coffee berry disease, immature or over ripe cherries must be separated and sold as low grades, returning a low price.

There are generic differences in taste attributes between washed and natural coffees and both are required for different market segments: wet processed coffee yields a 'softer' cup with less body and higher acidity while the 'arabica naturals' excel in their body and bitterness while lacking acidity. Within the classification of washed coffees there are two commercial market segments: 'Colombian milds' and 'other milds', a distinction that is delimited by origin. Either may or may not be fermented and the 'other milds' characteristically have more body and less acidity than 'Colombian milds'.

4. Coffee Fermentation:

Coffee is fermented, as mentioned above, to ease the removal of a layer of mucilage from the seed/inner integument to which it adheres. This is not to say there are no taste implications to this step. In contrast to coffee, the fermentation of cocoa is required to develop the flavour of the product though much of this is apparently accomplished by cocoa enzymes, rather than microbial activity. In coffee too, it has long been held that fermentation has a beneficial effect on flavour but lately, this has been disputed and many quality experts now accept the contention that mechanically washed coffee (with no fermentation) can be of comparable quality to the fermented product. What is beyond dispute is that badly conducted fermentation can result in disastrous losses in quality.

In general coffee fermentation is conducted as 'dry fermentation' where the mass of mucilage and parchments are not covered with water. The temperature of either of these processes is scarcely raised above ambient temperature reflecting the lack of oxygen diffusion to the heart of the mass. In contrast, fresh cherries held in woven sacks, an arrangement that has about 50% space, can heat to over 50°C within 36h. From a taste quality point of view, the fermentation step and operations either side of it (pulping and washing) are said to require conformance to certain criteria.

Firstly, the fermentation mass must comprise uniformly parchment coffee with a minimum of crushed or naked beans, skins and un-pulped coffee. Crushed and naked beans indicate beans with severe insect damage and/or a pulping machine being set too narrow. Presence of skins suggest the pulping machine is in need of maintenance and/or the water feed was too low. Un-pulped beans suggest that the pulper was set too wide and/or the removal of dried fruits has been ineffective.

Secondly, the fermentation must be concluded as soon as possible after sufficient mucilage degradation has been accomplished. This is ascertained by rubbing the parchment between your fingers to note whether the grittiness of the parchment surface can yet be felt.

Thirdly, after washing, mucilage must be completely removed from the parch before drying. Curiously, a product called *descascado*, produced with no attempt to remove mucilage, being pulped and immediately dried, can be a coffee of the highest quality.

The most important of these conditions is the temperature and the length of the fermentation. As mentioned above, coffee fermentation is not significantly self-heating so prevailing climatic conditions control temperature. The period of fermentation, in practice, can only be concluded when it is possible to take the coffee to the next two steps: washing and either soaking or drying. This normally occurs first thing in the morning since the afternoon and evening is reserved for pulping operations. Given that pulping always takes place in the late afternoon through the evening and requires everyone's attention, fermentation periods will tend to be about 18h, 40h or 64h. Robusta usually requires at least one day more than arabica.



Fig. 3 – a) Freshly pulped coffee accumulating in a fermentation vat, b) Dry fermentation in mid-course, in this case, covered by sisal sacking, c) Typical output of a pulper, note various particles that ideally would not be present in the fermentation mass, d) Complete and incomplete mucilage removal, e) Washing coffee in channels



5. Microbiological aspects:

The outcome of a process like fermentation is a consequence of what goes in and what conditions are experienced during the fermentation. We have seen that there is about 8.5 kg of sugar in the pulp of 568kg of pulped coffee and another 6kg of pectic substances. The balance of the 17kg of dry matter is ash, amino acids, cellulose and so forth. Most of the organisms are provided by the mucilage community with some from the processing water and incidental skins, etc. However, the conditions, as they develop, provide exceptionally powerful selective pressure toward fermentative organisms that can thrive at low pH. The fresh mucilage has a pH of about 6.5. This falls rapidly to a minimum of about 4.1 to 4.3. Although data is lacking, it is clear that oxygen tension falls with the fall in pH, both concomitant with growth. Typical of food fermentations, the 'wild' microbial flora of the raw material changes quickly and completely to species that were present, but rare, in the fruit-inhabiting community.

Studies of 'wild' fermentations are very arduous to conduct because of the sheer numbers of organisms and taxa and the difficulties in accurate enumeration and identification of them. The nomenclatural problems of synonymy and telomorph/anamorph names make comparing different studies difficult. New methods based on DNA PCR amplification and gel electrophoresis which allows direct analysis of the fermentation liquor without an isolation step, may provide a means to solve these severe practical problems in future.

In general, the fermentation can be characterized as a mixed yeast/bacterial fermentation. *Kloeckera apiculata* (= *Hansenispora apiculata* = *Saccharomyces apiculatus*) and *Hansenispora uvarum* are reported to dominate the yeast population with other yeasts such as *Pichia kluyveri* (= *P. fermentans*) and *Kluyveromyces marxianus* (= *Candida kefir* = *C. bulgericus*). The yeast species are fermentative and the dominant species share the characteristic of only assimilating and fermenting glucose amongst the usual sugars tested to identify yeasts.

The bacterial side of the fermentation is conducted by lactic acid bacteria, some Enterobacteriaceae and *Bacillus*. The most common bacteria to produce pectolytic enzymes are *Pseudomonas* (*P. fluorescens*, for example) and *Erwinia* (*E. carotovora*, for example). Of these only *Erwinia* is fermentative and, in fact, the presence of *Pseudomonas* is difficult to demonstrate in fermentation liquors. In general, the lactic acid bacteria have been reported to be more numerous than the Enterobacteriaceae.

Analysis of several fermentations under the project "Enhancement of Coffee Quality Through the Prevention of Mould Formation" has shown that the balance between yeasts and bacteria can vary widely, such that some are primarily bacterial and others dominated by yeast. It is not clear how the outcomes of these two types differ, or why it should differ.

The conditions of low oxygen tension and high water activity dictates that the oxidative, mesophilic species of *Aspergillus* capable of OTA production will not thrive during fermentation. In laboratory studies, large numbers of spores, introduced into the fermentation mass at the beginning of fermentation did not result in any OTA appearing in the beans and the organism (*A. ochraceus*) could

not be recovered from the beans after drying. But this test is only valid for models where spores, let us say from the fruit skins or soil contamination, are the source of the OTA producer. In fact, a proportion of beans harbour these fungi, infected before harvest, and there is some evidence to suggest that fermentation can kill them in the beans. However it is clear that fermentation does not always do so. In other tests where pulping was delayed for up to six days after harvest, the protective effect of fermentation against OTA accumulation was not observed. This could be interpreted as there being some threshold biomass above which the mesophilic fungi can survive the fermentation well.

The presence of skins with the parchment is unlikely to affect the fermentation course with respect to OTA production. The presence of dry cherries, which go through the pulper due to their small size, present a different scenario. If we assume a greater development of OTA-producers could have occurred under the extended period of oxidative and mesohydric conditions of this material, the fermentation would not protect and significant OTA production could occur if not during the fermentation, then later during drying.

There are three classes of Pectolytic enzymes. Plants and fungi produce pectin esterases which remove methoxy groups of the uronic acids revealing carboxylic groups through which Ca^{+2} coordinates the chains. Certain fungi also can produce Pectin lyase, an enzyme that attacks the 1,4 glycosidic links of fully esterified (methoxylated) chains. Lastly, Polygalacturonase is produced by certain bacteria and it also attacks the glycosidic links but only of partially de-esterified chains or segments. The oxidative yeast *Cryptococcus* is common in the fruit and it is reported to be pectolytic but numerous isolates from coffee have been checked without a positive result. A few *Candida* species are also reported to liquefy Ca-pectate.

The role of microorganisms in taste defects of wet processed coffee is a matter of debate. Of the numerous defects often attributed to problems during fermentation, the three most serious are 'fermented taste', 'sour' and stinkers. But because fermentation can occur in the intact fruit, especially if harvested and not processed expeditiously, the same defects can arise in natural coffee and, by extension, in wet processed coffee where the fault was actually elsewhere than the fermentation step.

A fermented taste has fruity aldehyde tones; sour is likened to onion; stinker is a powerful foul taste, and a single stinker bean can effect several kilograms of product. Stinker beans have been attributed to the growth of *Bacillus brevis* or high levels of lactic acid bacteria and maybe fairly specifically associated with derivatives of methyl-butanoic acid, cyclohexanoic acid esters and S-containing organic compounds. Some compounds that can be traced to a defect also indicate the source where few organisms produce the compound. Earthy and mouldy odour can be attributed principally to 2-methyl-isoborneol and geosmin, respectively. These compounds are produced notably by species of *Eurotium*, a few other moulds and some actinomycetes.

6. Soaking:

In some processing chains, whether or not fermentation has been conducted, a soaking step is sometimes applied. This is sometimes called secondary fermentation where a fermentation step is included in the process or fermentation where mechanical mucilage removal has been used. After mucilage removal the parchments are held under water for a period from overnight up to, rarely, 48h. The principle effect is to cause the beans to become more uniformly dark blue-green, a desirable physical character that itself has no taste implication. The colour is the same as that generated by the hydrated bean in response to physical injury, say damage by a coffee berry borer or cutting with a scalpel. The colour is likely to be a hydrolysis reaction akin to the chlorogenic acid reaction – it is not chlorophyll production.

Some authorities claim that soaking removes or reduces any harsh 'edge' the cup may have but, if true, it is unclear whether this is due to leaching (some slight leaching has been reported), or the metabolism of the seeds in essentially anoxic conditions. For coffee without this 'edge' there is no change in cup quality for up to 7 days, according to one study. The harshness is usually attributed to phenolic compounds so the implication would be that, through one mechanism or another, certain phenolic compounds are removed or altered.

After washing of the parchments, considerable yeast and bacteria remain on the surface and, with the yeasts, even in the bean tissue. However, there is very little substrate for microbial growth so metabolically, this period under water, is quiescent. Short periods of soaking do not seem to be associated with flavour defects outside of the use of tainted water for the soaking.

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