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The Microbiology of Coffee Processing.

A four part series, the first two being published in the PNGCRI Coffee Research Newsletter 1998-99.

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The origins of coffee go back more than 1000 years, allegedly to 'Kali' the Goatherd. For countless generations the processing of coffee cherries into high quality 'green bean', has been an art and not a science. It was carried out according to rules of hygiene and basic cook book art, keeping everything clean and doing it the way you were taught, by your predecessor, or you read about it in 'Wellman', 'Sivetz' or 'Wilbeau'. It was less than forty years ago that that scientists in the EAIRO, the East African Industrial Research Organization, the combined research facilities of the major African coffee producing countries, began to write that the fermenting of coffee mucilage was not just a chemical reaction that happened, but that it was all controlled by microorganisms and the enzymes that they produced. Despite the forty years, that knowledge has not yet seeped down into the coffee text books. The only quick reaction was the appearance on the coffee market of pectolytic enzymes such as Cofepec and Ultrazym. These products however, were not researched and designed for quickly fermenting coffee, they were repackaged products which were already on the shelves of the chemical companies, designed for other purposes such as clarifying beer and apple juice, improving the quality of wine, and increasing the juice extraction rate of oranges and apples etc. And they were so priced accordingly. Of that more will be said later.

Virus, Bacteria, Yeasts and Moulds,

We are all familiar with the processes of softening fermenting, rotting or putrefaction and disease caused by the various microorganisms which are usually classified into the above mentioned four major types. However, for the production of coffee the smallest in

size, viruses, can be disregarded.. Bacteria are the second smallest, they like to live and work in damp or liquid places, and in good warm conditions they will each divide and double their numbers every 15-20 minutes. It is certain types of bacteria which we need to encourage, for the fermentation of quality coffee.

Only slightly larger than the bacteria and slower to reproduce themselves, around 30 minutes per generation, are the next biggest category the Yeasts. To those people who home brew and make their own bread, yeast appears in mass as a white pasty solid, or as dried granules which disperse in the brew to make a cloudy sediment. Individual yeast cells are right on the limits of human vision. If the conditions are not right for bacteria to grow quickly, then it is often the slower growing yeasts which will take over the action. And this can spell lots of problems for the coffee processor.

Yeasts will first of all produce alcohol, but from a diet of mucilage rather than straight sugars they will also produce larger quantities of the various aldehydes and ketones, that in alcohol brewing terms creates bouquets or the 'nose', and in coffee terms spells 'fruity flavour.' Then as we all know, if the brew is left for too long the alcohol goes on through to vinegar and we are left with 'sour coffee'.

The largest in size of the microorganisms are the moulds or fungi. We are all familiar with the white cotton wool fuzz that grows on old fruit or stale bread. Within a few days the white then changes colour to black and blue, green or hues of red and yellow as the mould produces thousands of millions of coloured spores, which one puff of air will disperse into the atmosphere to drift for miles before they settle. The fact that it takes 3 or 4 days for those mould spores to germinate, grow and reproduce, albeit in such large numbers, means that anywhere where the conditions are alright for bacteria and yeasts to grow, then the moulds just cannot compete. They are still there in their original numbers but you just don't see them.

They All are Everywhere!

It is not only the mould spores however that can travel. When those lovely liquid growing conditions for bacteria and yeasts start to dry up or become less habitable, then both of these microorganisms will go into a kind of hibernation and also produce very resistant spores, just like the moulds. Every breath of air across a garden or plantation will carry millions of these microscopic embryos which will be caught on the sticky surface of ripe fruits. Most of these spores actually come from the soil and are an intrinsic part of the dust. Good dark healthy soil has millions of micro-organisms per cubic centimetre. It only takes a few minutes in the warm humid atmosphere of a picking bucket or bag with damaged cherries oozing sugary juice everywhere to create an enzymatic powerhouse of germinating spores of all kinds, each eager to outdo the other, take control of the situation and reproduce themselves ahead of the rest. It is these germinating microorganisms that cause the heat in a bag of picked cherry.

So, there is little point in trying to keep a factory super clean, although basic cleanliness is still desirable, because both the good and the bad micro-organisms are all there on every cherry itself, a dynamic equilibrium just waiting to happen.

Achieving Good Fermentation:

For good fermentation the kind of microorganisms that we want to encourage to outstrip the rest are what in plant disease terms are called the soft rot or brown rot bacteria. These types principally belong to the families of Erwinea, Kliebsiella and Bacillus, all of which cause rots and decay. We are familiar with the soft brown spots that happen on

injury to ripe fruit, and soon lead onto a mess of rotten slimy fruit pulp. Once the cherry skin is broken then the firm texture of the fruit created by pectin is destroyed by liquid enzymes, i.e., bacterial saliva, and the organisms can then spread quickly through the soft liquid environment which they have created for themselves. The fact that we remove the skin and expose the mucilage in the coffee pulping process just makes it happen all the quicker and of course the cleaner.

I should at this point also comment on the 'new' semi washed process being advocated by South American countries as a significant step ahead of the old dry process, where cherries are allowed to dry out and the dried skins and hulls are removed as 'husk' in one operation.. With the semiwashed system, the coffee cherries are pulped and then instead of traditional fermentation, the mucilage is stripped off the beans by a mechanical abrasion process in a demucilator. Of course Bentall did it years ago, with the 'Aquapulper'. This does make the processing of coffee a lot quicker, but it does not take the mucilage out of the crevices and more particularly the centre cut. It is the centre cut, exposed by the roasting process, which coffee buyers use to check for quality, and the discoloured mucilage that they find there marks down the coffee 'Semi washed' is certainly a big improvement over dry processed coffee, and that's the way that Pinhalense and Penagos market it, but it is still far behind a fermented and fully washed and soaked product in terms of mildness and quality. However, all one has to do with a modern South American pulper, is to is to store that demucilated pulpage for a few hours, to allow the bacteria to work their way into the centre cut, then wash, soak and dry it in the usual way, to alleviate any such loss of quality.

Of much greater significance are the even newer 'ecological' pulpers now being produced by the same South American manufacturers. These machines do save water and they do reduce the pollution load into the waste water. However, more particularly, they do not leach the soluble sugars out of the pulp. This raises the value of the pulp waste and allows it to be easily converted into non toxic animal silage feedstuff, which will be discussed in the last chapter when we look at wastes treatment. We will then also look at the build up of colour in the pulping water, which causes no harm at this stage. Even if the recycled water running back through the pulper is black! The parchment will dry as water white!

Enzymes:

Part of the confusion in the minds of earlier research people was that in the process of normal maturation, all fruits produce their own internal supply of pectolytic enzymes which soften the fruit naturally as it ripens. Although these 'natural' enzymes will act in concert with the bacterial ones, they do act very much slower and under different conditions. The inside of an intact fruit is anaerobic, and so the natural fruit enzymes tend to act better under water. The subject of 'enzyme kinetics', finding out the relative speeds with which various enzyme systems can react and work was the breakthrough in research which has put emphasis very heavily on the side of micro-organisms for achieving quality fermentation of coffee. Bacterial pectolytic enzymes starting on the fruit surface act much faster in aerobic conditions, or where there is oxygen dissolved in the water. Yeast enzymes are somewhat ambivalent, but tend to prefer anaerobic conditions. So, if it is necessary to keep fermenting coffee under water for other reasons, then don't let the water stagnate for more than a few hours 5-6 at the maximum. The dissolved oxygen content in the water, however small it may appear to be, is vital!.

What is an Enzyme.

An enzyme is a biological catalyst, usually a complex organic protein, which enables other chemicals to react or change but does not get used up or converted itself. Therefore, even a very small amount of an enzyme can continue to work over and over again creating changes at low energy levels and without any apparent effort. Depending on their origin, enzymes differ remarkably in their preferred working conditions. We have talked about oxygen levels or aerobicity, and the two other major factors involved are temperature and acidity.

Looking at Temperature:

A major rule of thumb for biological chemists is that between say 0 and 50^{o}C, the range of most living things, a rise of 10 degrees will essentially double the rate of any chemical reaction. So, the warmer the water supply the quicker the coffee will ferment. If it is possible to get the factory water supply up to around 24-25 degrees Celsius, then it should be possible to pulp, ferment, wash and soak coffee in less than 12 hours. The easiest way to do this is to recirculate ones pulping water. Pulping water cannot be used for other purposes, but its use can be extended or recycled round and round in the pulper for 2-3 hours, with extra water being continually added to make up the losses. Every drop of water recycled in the pulper is that much clean water that has been saved.

However, most importantly, by recirculating the water, the temperature, sugar levels and the enzyme concentrations are also raised, and no matter what hour pulping is finished, as long as it is before midnight, you can start washing out all that coffee first thing next morning. Even though the pulping is started with cold water, that first pulpage goes in the bottom of the tank, and all the warmed recycled water put through later on will have drained down through it to bring it up to the same as the rest of the tank. If the tank is too deep, then despite the continued drainage, conditions may become anaerobic at the bottom and normal fermentation will be slowed down. Nevertheless, by constantly recirculating the pulping water, that which is draining down through the tank will carry entrained and dissolved oxygen down with it, sufficient to keep the enzymes working right to the bottom.

Letting pulped coffee go solid in the tank will slow down the bacteria, encourage the yeasts to take over and fruity flavour will be sure to result. Prolonged fermentation times, measured in days rather than in hours, are usually a temperature problem, but acidity and lack of oxygen may also be involved. If the fermenting pulpage that has stalled is washed, that is, pumped from one tank to another by hosing the solid pulpage with warmed water and then putting everything through the pump, the mix will be re-aerated, the liquefied mucilage allowed to drain away taking a lot of acidity with it, the soft rot bacteria will be encouraged to win their battle against the yeasts and normal fermentation will recommence.

Use Warm Water:

A good way to both warm the pulping water and aerate it, is to pump the clean water supply early in the day and run it over a roof, preferably painted black., and then down through the gutters and spouting into a low level holding tank. From there the normal pumping systems can use it and recirculate it until pulping is finished. By the time that the cherry picked in the heat of the day comes into the factory, it is usually 25 degrees centigrade or more, largely due to intensive bacterial fermentation. The aim should be to keep it as close to that temperature as possible. This is where the old traditional idea of using 'clean' cold water straight out of the river and using it only once through the system should be laid to rest! recycle Recycle RECYCLE! However, after 2-3 hours, or when pulping is finished, that very syrupy and highly discolored water must be discarded. Also, any tanks, channels and pipelines that have carried this recycled water must also be

hosed clean at the end of the day. Failure to do this will allow the accelerated buildup of a firm mucilage coating on the walls of anything contacted. That coating is a 'capsular' protection for the millions of bacteria who made it. Every big factory should be able to buy itself a 'water blaster' to counteract the build up of such films on walls contacted by coffee waters.

By the next day the used pulping water will not only be very acidic, but it will also be highly anaerobic, and therefore nasty anaerobic bacteria like the Clostridium family may have started to multiply. Clostridium normally spells 'onion flavour' The acid/vinegar aspect however leads us into the last point of acidity.

Fermentation and Acidity:

Pectin degrading and solublising enzymes from bacteria can only work in essentially neutral conditions at a pH of around 7. Let the pulpage go below pH6 and one is in trouble. In contrast, yeast and fungal or mould pectolytic enzymes prefer much more acid conditions. The usual causes of a very slow or a halted fermentation are low temperatures, low or acid pH and anaerobic conditions. So, a tank of coffee that really hangs up on the fermentation, after pumping it, then becomes an ideal case for the use of the acid loving fungal based 'Ultrazym' which works best at pH5. At pH 7, half of its effectiveness is gone! (See, Figure 1.) A surprisingly small amount, less than half of a 50gm packet costing around US$10-00, if well mixed into up to 20 tonnes of coffee by again pumping the stalled pulpage/fermentage from one tank to another, will really work wonders in the space of 2-4 hours, also depending, on that initial factor the temperature. To explain this figure of pH, the chemical measure of acids and alkalis is a logrithmic number. So that a pH of 5 is 10 times more acidic than 6 and 100 times more than a pH of 7, which is considered to be neutral. Pure water has a pH of 7, and going past that, pH 8, 9 or 10, is becoming very rapidly an increasingly strong alkali.

Making Your own Enzymes:

Enzymes are the biological catalysts which living things use to make biochemistry happen. Their names usually end with the suffix '-ase'. However, these precise acting catalysts also need to work in precise conditions. The bacterial enzymes that break down mucilage or pectin need to work in essentially neutral conditions, whereas as mentioned above, all of the commercial pectin enzymes such as Cofepec and Ultrazym are made from moulds or fungi, and like to work in acid conditions. For fermenting coffee mucilage, natural bacterial enzymes are much more suitable. Even though there are no bacterial type pectinases on the commercial market, it is relatively easy to make your own.

While it is equally as effective to use normal pulpage for this process, it is a pity to waste good coffee beans, when unfilled beans, i.e. The lights and floaters are just as effective. The only problem of course is how to get an adequate supply of them. If an Aagaard pregrading machine is not available, then one may be able to close off the bottom drain and flood the first tank that the pulpage is going into for long enough to rake sufficient floaters off the surface, either through a flotation notch or into a bucket. Then the drain can be opened, to recirculate the water back to the pulpers again. About a bucket of floaters are required for every large fermenting tank.

All that is required is to fill the bucket of floaters with water, put a lid on it to keep the solids under the water, and stop the fruit flies, and then give it a brisk stir with a stick for a minute every day for five days, long enough to digest the initial acidity. It should then be possible to decant the surface scum, strain off the beans, which now must be discarded, and

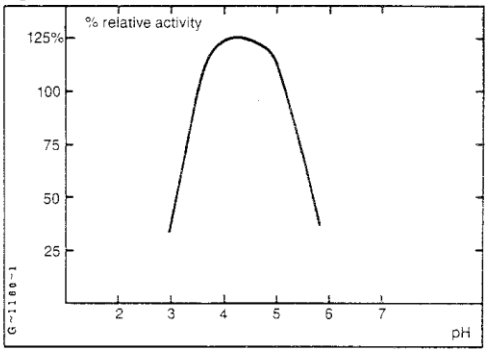
have about half a bucket of clear yellow liquid which is full of potent bacterial enzymes. If the pulping water is being recirculated, then the brew can just be mixed into the pulping water. This will assist in maintaining rapid fermentation even if the water is too cold.

If recirculation is not possible, then the brew should be diluted sufficiently to spread it evenly all over the top of the tank of fresh pulpage when pulping is completed, and then allow it to drain down through the tank. Using either of these methods, overnight fermentation can be achieved, 6-8 hours, thus allowing a 24 hour turn around and the reuse of those same tanks for the next days pulping. This process can double the capacity of an existing factory with limited tank space. The only problems that may occur is when the pulpage is allowed to go solid in the tank.

The use of a hand held pH meter and a thermometer is desirable for new or trainee managers but not essential. A similar type of ORP meter to check aeration levels even less so. The old hand can put his hand in the water, slurp a mouthful and spit it out to arrive at just as good a decision.

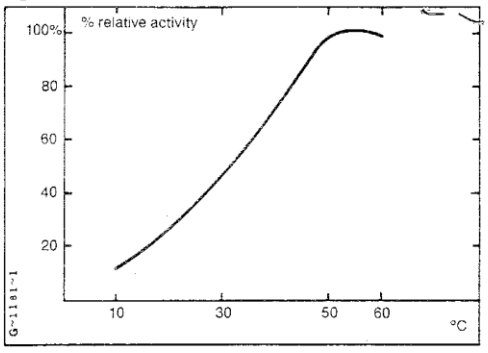
Some Characteristics of Ultrazym

Fig. 1



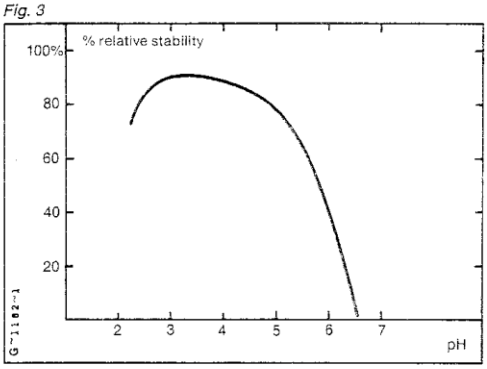
Pectinase - activity versus pH
Depectinisation of apple juice at 55°C
Reaction time 100 minutes

Fig. 2



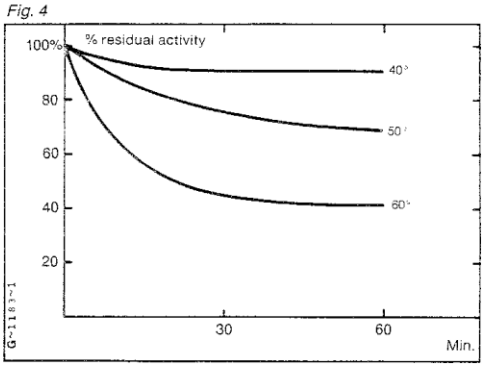
Pectinase - activity versus temperature
Depectinisation of apple juice, pH 3.5
Reaction time 100 minutes

Fig. 3



Pectinase - stability versus pH
In aqueous solution 20 min 50°C
Remaining activity measured by the depectinisation of apple juice at 55°C

Fig. 4



Pectinase - stability versus temperature
In aqueous solution, pH 3.5
Remaining activity measured by the depectinisation of apple juice at 55°C

The activity is measured by the depectinisation of a non-clarified, pasteurized apple juice at 55°C, until no further pectin is precipitated by addition of isopropanol (1 part juice + 2 parts isopropanol) within 4 minutes. The standard juice contains 0.4 g of pectin/l with an esterification degree of 95%. The pH is 3.5.

3 g of a product with 1000 FDU/g is capable of depectinizing 100 l of the standard juice at 55°C within 2 hours.

Figure 1.
Characteristics of the Fungal Enzyme. Ultrazym.

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Chapter 2/.
TAINTS AND OFF FLAVOURS.

In the first part, we discussed how one can get a better understanding of how coffee is processed, by looking at it in terms of microbiological action. The race is on between the

soft rot bacteria, who do the best job of breaking down the mucilage, and those yeasts and moulds, which can continue on, if not washed away with the fermented mucilage, to cause off flavours in the finished product. To encourage those beneficial bacteria, warm water, >20oC and preferably around 25oC, neutral conditions and a good supply of oxygen are required throughout the fermenting tank. It is sometimes confusing to the layman to think that coffee fermenting under water can have sufficient oxygen, but we only need to think of fish and how they live quite well on the 9ppm of dissolved oxygen in open water, and make sure that we wash our coffee and change the water at least once every day, to keep up that supply of dissolved oxygen. It must be reiterated however that the fastest action comes from allowing the tank to drain freely and atmospheric oxygen to permeate the drained mass, which should have open spaces between the mucilage on the beans. Once that space is lost, the tank goes solid, movement is lost and the mass becomes anaerobic.

Fruity flavour and Sour coffee:

Even though the beneficial bacteria can get an early lead in the race towards complete digestion of the mucilage, once they are shut down, or immobilised and their immediate food supply is used up, then the slower growing yeasts can overtake them and redigest the soluble mucilage, along with the sugar groups that are attached to it, on a stage further into alcohol. As in traditional brewing terms, the yeasts go on to produce not only alcohol but also that same bouquet of fruity flavours that makes every wine different. If the coffee is washed, then the alcohol will be removed, and a fresh supply of aerated water will keep the bacteria ahead in the race. However, leave the fermenting coffee in the tank for too long, or let it solidify, and the yeasts will take over, the fruity flavours will establish, and the alcohols will carry on to be converted to vinegar type short chain volatile acids, which spell 'sour coffee'. The point to make about this is, that the onset of fruity flavour is not tied to time, but to the completion of fermentation. If your coffee ferments to completion in 8 hours, then you will start to get fruity flavour at 12 hours. If fermentation takes two days, then the onset of fruity will commence in 2.5 days. The moment that fermentation is complete final washing should commence. Early stage fruity flavours can still be washed out before they have penetrated into the oils in the bean, so there is usually a few extra hours of grace, before even the most thorough wash and soak cannot still recover a batch of 'overfermented' coffee to finally produce fine parchment.

Alcohol:

In answer to the obvious question, yes it is possible to make potable alcohol, of sorts??, from liquefied coffee mucilage and coffee pulp. However, it has to be separated from the beans as quickly as possible, and heated up to the point where all that plethora of wild yeasts and bacteria are destroyed, but not so hot as to coagulate the mucilage oligosaccharides and take them out of solution. Then, even with good brewers yeast being used, there will still be a small but significant proportion of Methyl or 'Wood alcohol' produced. This is because coffee mucilage, has a high proportion of methyl as well as ethyl sugar attachments in its structure. Ethanol is what we like to drink, but Methanol is the really sore head stuff that sends one blind in not so large quantities, and only takes a 50mls slug of the straight stuff to kill you! The final cut is that methanol is very difficult to separate from ethanol, and that is why they use it to denature ethanol into methylated spirits for cheap industrial usage.

When they can genetically engineer coffee to produce a demethylated mucilage, as well as decaffeinated beans, I will be the first to let you know! Until then, you will have to abstain, or else put up with the headaches!

Floral, Winey and Herby taints:

Like fruity flavours, there are many specific 'bouquet' type taints that occur on the side of an alcoholic ‘wild yeast’ fermentation. The alcohols are more water soluble, and volatile enough to be removed in the washing and drying processes, but some of the more oily type aldehydes, ketones (fusel oils) and perfumery base type chemicals can pass back through the parchment skin and dissolve into the essential oil of the green bean. They can then reappear at roasting. When the buyers want them they are good! When they don’t want them, they will drop the price on you every time!

Onion flavour:

There are of course many different organic chemicals which can be produced by a variety of other bacteria, as well as the yeasts. The onset of onion flavour for instance, comes about when the ratio of soluble sugars to less soluble pectins becomes too low. The initial quick build up of beneficial bacteria is fuelled by the relatively high levels of detached sugars present within the ripened mucilage. If however, excessive fresh water is used in pulping, or, more particularly by the use of an Aagaard pregrader, then most of these soluble sugars are leached out before normal fermentation is completed, then the beneficial soft rot bacteria can be overrun later in the fermentation not only by the yeasts but also by other bacteria which produce higher acids, propionic and butyric acids, the root cause of onion flavour. Once again, these faults can be minimised by recycling the pulping water and also the Aagaard water should one be used. Maintaining a high level of sugars and enzymes in the water will speed up the normal bacterial action. However, it must also be said again, that the moment that the recycled water starts to go thick and ropy, ie. every few hours, this recycled water must be discarded and fresh water be used to start off again on a new fermenting tank, or the following day.

Earthy, Musty and Phenolic taints:

The third group of micro-organisms relevant to coffee processing are the Moulds or Fungi. As already stated, if there is sufficient mucilage present to keep the bacteria and yeasts multiplying, then the moulds do not get a chance to even germinate , let alone to grow. It is usually only after the parchment has been washed completely free of mucilage and put out to dry, that mouldiness can begin to occur. Indeed, the cleaner and the more well soaked the parchment is, the more likely it is for moulds to develop on damp coffee. There is one theory circulating, that the recent cause of Rio flavour in PNG is linked to the drive towards high quality well soaked parchment.
The practical solution to these kind of musty, mouldy taints, including the dreaded Rio or Rial flavour, is to get ones clean wet parchment skin dried as rapidly as possible before any mould spores get a chance to germinate, particularly in the centre cut. If the morning that one intends to put wet parchment coffee out to dry is wet or dull, then the coffee should be kept soaking in the tank, under a fresh batch of clean water, until the sun comes out and the surface water can be dried off as soon as possible in one non stop operation. Mould spores cannot germinate under water, and they cannot germinate on the surface of dry parchment. The danger is dampness, and that can be very insidious. Once a mould spore germinates, it puts out a series of thin hypa or threads that will bore straight through wet parchment to get at the juicy wet beans inside, and once inside the parchment barrier, all the drying in the world will not stop it.

Plastic Sheets and Coffee ‘Sails’:

Once coffee has dried enough for the bean to begin to shrink and separate away from the parchment layer, there is that high humidity “micro climate” in under there, fed by moisture coming out of the still wet core of the bean and

allowing all sorts of odd things to grow, thrive and do a lot of damage right underneath the parchment where we cannot see it. So, even on a wet day, every brief period that the rain stops, even for only 10 minutes, at least one or two sails must be opened up, shaken and rewrapped, in short order to dispel the warm damp air inside, replace it with cold damp air and minimise on mould spore germination. During the course of the day, it should be possible for each drying sail to be opened up at least once, even if only for a few seconds.

Smallholders and Rio flavour:

Smallholders may think that they can avoid this problem, because they only put their coffee out to dry when the sun is shining and it is worth the while of someone to sit and watch, that no one steals it. However, the danger area here is when half dry coffee is stored in a sack, and kept wrapped up inside a nice warm house, while waiting for the sun to shine. Every morning and afternoon during bad weather, the bags should be taken out and the coffee poured into another bag in order to get rid of the warm damp air. Once emptied, that bag should be well shaken and turned inside out before being refilled from the next one. So, only one extra bag is needed to begin the process.

Looking at Figure 2, the safe level to dry coffee to is around 11% . This should prevent the germination of those mould spores that have been wiped onto the coffee by the hulling and polishing processes. However, if the 'Relative Humidity' of the atmosphere is greater than 60% which is the equilibrium figure for 11% MCDB, then the coffee will gradually take up more moisture until it is once again in equilibrium with that level of R.H. Mix overdried green bean or parchment with a similar amount of under dried material, and in three days od storage they will have evened out to the one constant figure.

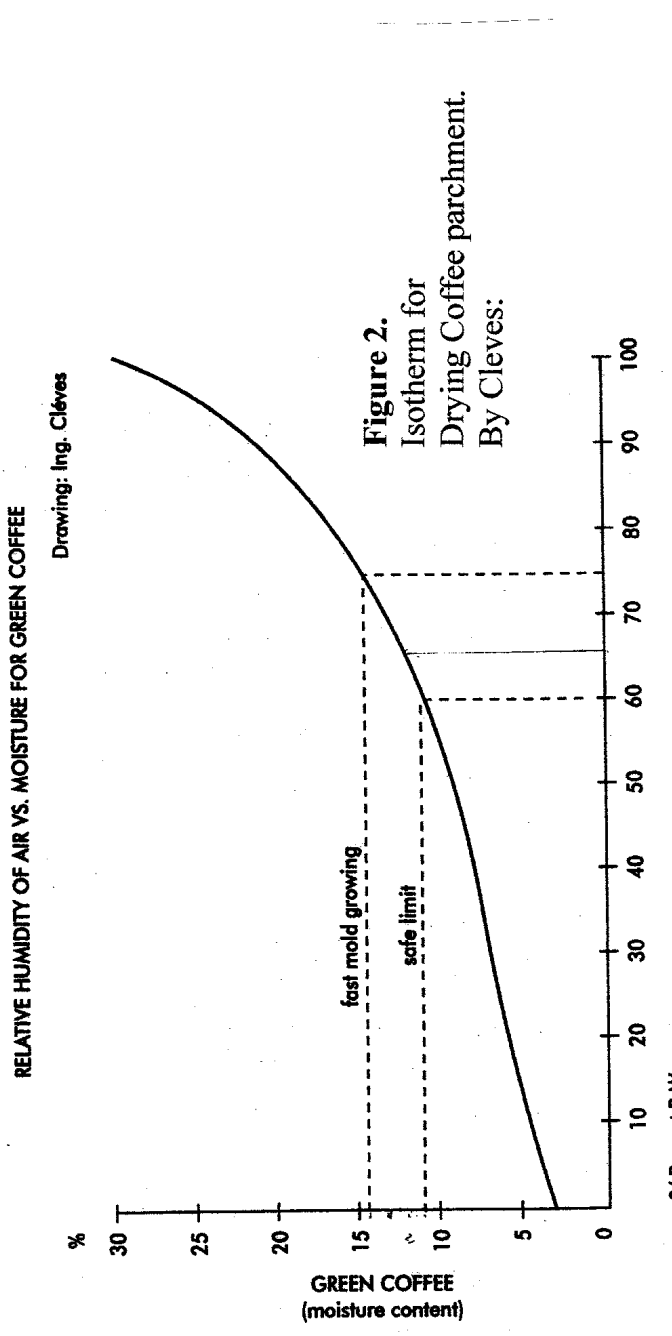

Figure 2. Isotherm for Drying Coffee parchment. By Cleves:

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Café Britt Hermetic Cocoon Storage Trial

Conditioning Bins:

Conditioning bins are an ideal way to raise or lower moisture content to a fraction of a percentage point. A normal domestic table fan has sufficient pressure to blow air through a bed of up to 3 metres of parchment in a bin at a rate of flow of around 5 metres/minute. Pick the time, day or night, when the relative humidity of the air is the right way to raise or lower the M.C., and put the fans on a timer switch. I know a case

where a Factory Manager faced with very low R.H. local conditions, even at night, and a batch over dried coffee, poured an inch of water over the floor under his bins and blew air over it until he had gained the two percentage points required to get back to his desired figure for maximum weights and profitability. .

Stink coffee:

For good quality coffee production, the factory water and the equipment must be kept clean, but as in terms of the Onion flavour and Rio flavour mechanisms, it is not just a case of the cleaner the better. Cleanliness can be overdone! Nevertheless, the cause of stinker beans is not from unusual micro-organisms but from excessive over fermentation with normal ones. Each day the factory tanks and machinery must be cleaned to make sure that old beans are not retained for several days in cracks and crevices to come out and contaminate a later batch of coffee. Such extreme 'over fermentation' of beans left in small pockets will germinate the coffee seed, which if then left under water rapidly dies, and leaves a black spot under the parchment. If the bean has been skinned in the pulping, then the sprout falls out to leave a hollow pit in the end of the bean. These dead beans then rapidly putrify and develop a cheesy and evil smelling texture which is very evident when one is squashed or cut. Contamination with only one or two such stinker beans can spoil a whole batch of good coffee.

Other flavours:

For the sake of completeness one should also mention those off flavors and taints which are not caused by micro-organisms. Green, grassy and some harsh flavours are caused by picking and processing immature cherry. The problem is not so much to do with really unripe green cherry which will not pulp at all, because that stuff gets nipped by the pulper and discoloured and is then easily removed by hand picking or a good colour sorter at the green bean stage. The real problem occurs both early and late in the season, when lots of cherry looses its green colour but does not go completely and evenly red all over. Called ‘under-ripe’ coffee, this cherry will pulp easily, but the silverskin, which extends right away inside the bean, is still full of green chlorophyll. This is very easily seen in fresh wet washed parchment which is transparent enough to show up the greenish colour of the silverskin underneath. The answer here is to sun dry the coffee as much as possible, so that the ultraviolet light can bleach out the greenness in the silverskin. When botanical leaf specimens are pressed and dried in the dark, they remain green. But leaves dried, out in the sun are bleached enough to go brown. However, this is not the complete solution because the green chlorophyll laden silverskin extends right inside the bean itself, where sun light cannot really get at it. Cut open an underripe bean to see for yourself. Slight greenness often fades with time, and is no longer evident at the final destination, but a lot of under-ripeness will allow chlorophyll type chemicals to be absorbed back into the oil fraction of the final product.

Bagginess, oiliness and coal tar taints generally come from contamination. Cheaper types of jute bags have excessive amounts of, or low grades of, 'batching oils'. These are the oils used to lubricate the bag making machinery, and manufacturers of high quality jute sacking always lubricate their machines with vegetable oils to avoid this problem. Over lubrication of drying machinery and drying coffee on the road side are also possible sources of this problem. Smoky flavours tend to come from leaky air heat exchangers, and earthy, dirty, foxy and similar taints and appearance are from too much dirty skins in the parchment, not only during over fermentation, but also at the time of hulling, when the green bean is screwed up against the dry but still dirty skins and parchment hulls. This is also the time when the main load of mould spores left on the dirty parchment surfaces are wiped back onto the surface of the beans for subsequent damage to occur downline during

shipment.

Chapter 3. Tertiary Technology.

In the first two articles in this series we have looked firstly at the wet processing and then at the drying of coffee parchment, and how the way in which these operations are carried out can lead to a range of problems in maintaining a good quality product. However it does not finish there. Even at the stages of hulling, grading and shipping coffee, when the moisture content of the green bean is so low, <12%, that it should be totally protected from any bacteria and yeast infections in terms of its low 'water activity', it is still helpful to look at the problems involved, in terms of how they may be intensified by the presence of microorganisms, particularly the Moulds or Fungi. The basic causes of the problems of premature aging and deterioration in the quality of polished green bean are elevated humidity and temperature. That is, the sweating of coffee in the drying fields and the overheating of green bean by overly rapid mechanical drying, hulling and polishing.

Moisture Effects:

The easiest way to understand these problems is to look at our own bodies. Even on a very hot day, if we are out in the wind, our skin remains dry despite the fact that we are keeping cool by evaporating a lot of water. The thing is that that liquid moisture evaporates from under the skin, it is under the skin that the cooling effect occurs, and only a gaseous vapour of practically pure water leaves the pores of our skin.. However, restrict the flow of air around us to raise its relative humidity, and wrapping ones self up in a plastic raincoat is the extreme case, then we still lose the same amount of moisture, but it comes out through the skin not as a gaseous vapour but as the liquid we call sweat, and it has little to no cooling effect at all, certainly from under the raincoat. Sweat however is far from being pure water. It is a solution of salts, sugars and other soluble nutrients, which then deposit on the skin surface, and makes ideal food for microorganisms. All the stale sweaty odours of the great unwashed, and the unpleasant sticky feel of our bodies when we are not clean, are the obvious result of a lot of unwanted microbial activity.

It is also pertinent to mention at this point that coffee which is left to soak in water for overly long periods is also subject to this same leaching process. With water outside as well as inside the bean, the transfer of soluble sugars and salts across the surface of the bean can also happen, even quicker than sweating. Some knowledgeable sources give a figure of 1-2% loss in the eventual weight of the green bean for every day that coffee parchment is unnecessarily in contact with water. Therefore fermentation washing and soaking times should be kept as short as possible. Nevertheless, do not completely do away with any of these processes, especially the washing and some soaking, or there will be an even more costly loss in ultimate liquoring quality for other reasons..

As stated, coffee beans are no different to the human body. The ideal way to dry coffee is to use conditions where the air surrounding the beans has such a low relative humidity that moisture is lost as a vapour only, leaving all the nutrients, i.e. sugars and salts, back inside the bean, to maintain its maximum weight for sale. However, let your coffee sweat, by leaving it wrapped up in a plastic coffee sail when the sun is shining, and everywhere a droplet of coffee sweat forms under the parchment and the silverskin, and on the surface of the bean itself, and there within a matter of days will be a patch of microbial activity which shows up as a spot of pale blue fluorescence on the surface of the hulled bean, when

it is placed under an ultraviolet light. A small U.V. fluorescent light, such as the banks use for checking signatures, is a very useful tool for a Factory Manager.

A further cause of U.V. pale blue fluorescent areas on freshly hulled green bean, is when the beans are crushed or damaged by impact with something solid. Overactive bag pulping by Smallholders, with a stone or a billet of wood is a major problem, especially when the bag is placed on top of something solid like a road. On the larger scale older type Kivu pumps with open impellor blades are bad for both skinning and impact damage of wet parchment, particularly when they have been speeded up by use of a modern four pole or even a two pole electric motor. The Original Kivu's ran with 6 or even 8 pole motors, ie. 800 or 600rpm.. (The modern 2,3,& 4" 'trash' pumps are a much better and far away cheaper option.)

If there is even a small gap between the front of the impellor blades and the front face of a Kivu pump casing, then the water sweeping back through the spaces will trap beans, so that they are pressure rolled through the gap by the moving impellor. Being soft and juicy they will spring back into shape, often minus their wet and still flexible parchment coating. When there are lots of skinned parchment appearing, check these kind of clearances in all your machinery. However, partially dried beans that have been crushed in this way will extrude watery juice from the damaged cells that is full of nutrients, just right for microorganisms to grow on.

Over time, these pale blue coloured UV fluorescent areas will be lost in the overall build up of the whitish frosty coating that typifies aged beans, and which glows white rather than blue under the same UV light. That frosty coating is a mix of microorganisms and oxidation products which inevitably build up on the exposed surface of dry green bean over a period of months. The best that can be done is to understand how to delay its onset as long as possible, or at least until the green bean has been further processed into roast and ground coffee.

Oil extrusion:

The major cause of that white U.V. fluorescence, is not moisture damage but extrusion and oxidation of 'oily' products. Green bean coffee has as much oil content as do peanuts. We are all familiar with the oily appearance of roasted peanuts or of over roasted coffee. The major problem for green coffee however is a bit more insidious. When coffee parchment is dried down to about 15% moisture content, the black colour of the drying bean starts to disappear, as the ratio of oil to water within the bean cells changes over from oil droplets in a water based system to the more concentrated water droplets in an oil based one, which should give that lovely blue/green colour of a premium product. From that point on, damage to the surface of the bean during hulling and polishing, will extrude oil rather than water based products, and the microbial damage to oily products fluoresces with a white colour instead of blue. Using a portable battery U.V. light, an astute factory manager can diagnose a lot of his own quality problems in this way.

Apart from over vigorous mechanical abrasion during hulling and polishing, just overheating the coffee in a hulling operation or in a dryer fired to above 50oC, will later on start to extrude sufficient oil emulsion on the surface of the beans to set those resident mould spores and other microbiologicals into action with an especially rich supply of food. This is primarily a problem of case hardening and micro cracking. When moisture is pulled out of the surface layers of the drying bean, faster than the moisture can move out from the still damp interior, the outer surface of the bean is hardening and shrinking over a still swollen interior. So, just like the cracking of parchment through the too rapid skin drying of wet parchment, the actual horny surface of the green bean itself is subject to some kind of damage that we call 'micro cracking' for want of any better words. Even though the

horny layer itself will disappear as the moisture evens up, those micro fractures remain. And that will allow nutrients to seep out onto the surface, to cause lots of problems down line. It is overheating in the huller however that is the major cause of premature aging. Over intensive polishing activity combines with the temperature rise, to scarify and remove the naturally antibiotic surface layer of cells on the green bean. This will allow fluids from damaged cells to slowly extrude out onto the surface. Some experts may want to argue that the subsequent reactions are purely the chemical oxidation and rancidity reactions of exposed oily biochemicals, but there is little doubt that those oxidative chemical reactions, that we call 'premature aging', are stimulated by the enzymes and activity produced by living microorganisms. Cross coupled experience, in the food industry, especially in the processing of nuts, such as walnuts, almonds, roasted peanuts etc, where broken and polished nuts are protected from such oxidation, usually termed rancidity, by application of a minute amount of a commercial antioxidant such as vitamin C powder, would lead one to make the suggestion that premature aging, and indeed any aging of coffee is preventable. However coffee, having several hundred more years of history in its traditional practices, tends to be very conservative in matters like this.

When freshly hulled and polished green bean has a warm 'greasy' feel, it looks really nice and has a translucent 'glow'. Nevertheless, it is already a major step on the way towards premature aging. There is often enough oil on the surface of such coffee to not only grow lots of mould but also react with the fine dust in the grading machine and make a kind of varnish which will build up on the screens and slowly reduce the hole sizes, unless they are checked and scraped clean at regular intervals. One has only to be accused of trying to pass an A-B coffee off as A grade, or a mixed A as straight AA, to learn a swift lesson about the need to continually check the screens in ones grader for build up of such varnish like deposits.

Bentall Okrassa type screw hullers, which have the hulling and polishing operation combined, are well known in the industry for overheating coffee. Separate the hulling operation from the polishing, and allow the green bean to cool between each operation is good practical advice to new players. Despite the number of Kaack, Pinhalense and other types of impact hullers which are lying derelict in older factories, there is some method in their use, to minimise both the temperature buildup and the scarifying action from intensive polishing. Also the destruction of that naturally microbial resistant surface layer of intact cells. The thing is that impact hullers tend to leave not only the silverskin but also that protective layer intact for as long as possible. Hence their use in the coffee Benificios deep inland in Brazil. This reduces the bulk and volume for storage and transportation, hundreds some times thousands of kilometers out to the coast, but preserves the natural surface of the beans for as long as possible, until that final polish and pack just before shipping. So, 'Combo' Hullers, primarily designed for those inland Beneficios, only do half the job. A final polish and grade is still necessary before export.

Lets get back to 'Impact' primary hullers:

A further good reason for processors of low grade coffee to look again at the use of impact type machines as the first stage in their hulling operation, concerns the problem of earthy tastes, and discolouration of their green bean product. These problems are largely caused by screwing up the essentially clean and protected beans with large quantities of dirty foxy coloured hulls, fragments of dried pulp and all those ubiquitous mould spores. Get rid of as much dirt and stained hulls as possible, by impact hulling with a good screening and recycle operation. This will get rid of the dirt and discolouration, without too much contamination of the beans. The oily

surface of coffee beans that are badly processed will dissolve a lot of dirt and discolouration and later allow it to percolate into the bean itself. So, impact hull, and then follow on with the SM14 or the old Okrassa huller in a minimal polishing operation on the separated beans, minus all the dirt. With the Okrassa, one should use either the steel end or the bronze end, but not both, to minimise the rise in temperature.

It is a mute point as to whether strongly attached silverskin, as in much Y2 grade parchment, will detach and catch fire in the roaster or not, but there is much to be said for minimal polishing even if the silverskin is very hard to detach. Papua New Guinea is one of the few countries that has to ship its Arabica coffee across the equator in the stuffy hold of a ship, and anything that will allow our coffee to open up in the northern hemisphere in as good a condition as that of our major competitors, can only be beneficial to our international image.

Storage conditions:

In the light of these points it should be clear that the only way to preserve coffee for as long as possible is to keep it in parchment form. Once coffee is hulled and more particularly polished, the aging process leading on to surface oxidation aided by microorganisms is inevitable. It can however be minimised, by dusting with antioxidants, as mentioned elsewhere, or by storing the processed green bean in conditions of as low a temperature and humidity as possible, to slow down the metabolism of that surface coating of oily foodstuffs by bacteria, yeasts and moulds. Moulds in particular are adept at growing on the surface of dry and very concentrated foodstuffs by using the humidity of the air as their source of moisture, and taking up only as much food as they require through their 'waterproof boots' that protect them from the low 'water activity' levels.

The typical illustration is the white fluffy mould that grows on the surface of an open jam jar, where the jam is so concentrated that the sugar would suck the moisture out of anything alive in real contact with it. Keep the lid on the jam jar, to control the moisture in the air and the mould cannot grow. Leave the lid off and you will have mouldy jam!

Nobody has yet built an air conditioned coffee store in PNG, but one day that will happen! Its not so much the temperature control that is effective, but the humidity control. In the meantime, there is much to be said for storing containers filled for export up in the Highlands, and only taking them down to the coast as late as possible.
Always cover piles of bags with an air tight tarpaulin, particularly in periods of high humidity weather. Keep a check on the moisture content of stored coffee.

A further possibility is to minimise on the use of bags by bulk filling of containers with an internal plastic liner which can be hermetically sealed. That sealed but still semi permeable liner will not only minimise the levels of both oxygen and moisture, and that means slowing mould growth, but it will also concentrate the percentage of carbon dioxide retained by the liner membrane. That too delays aging.

Indeed, in the major towns that have a plant for making welding gases, those plastic lined containers could well have much of the warm air purged out of them with cold and very dry nitrogen gas, that would bring a rapid reduction to all of these aging processes by cutting down on the metabolic rate of the resident microorganisms, just like CO^2.

The final word on the quality of our product is given, not so much when it is drunk by the consumer, but when those experts who count, the overseas buyers, make their assessment when they open up our product on arrival at their warehouse. There is so much that we could yet do, to maintain quality up until the container seals are broken, at that point. From then on we might well say, "its not really our problem!" But of course it

is always our problem, and we neglect it at our peril.

Chapter 4.

Wastes Treatment in the Coffee Industry. Making the Industry Energy Self Sufficient.

In the first three parts of this series we have looked at how Microbiology can help us to understand the problems of ; 1/. Picking, Pulping and Fermenting wet coffee. 2/. Washing and Drying parchment coffee. 3/. Hulling Polishing and Packing green bean coffee. This new biological view point is in terms of understanding how bacteria yeasts and moulds participate in what previous generations of Coffee Millers took to be basic "house keeping" processes, and just a matter of keeping everything clean and fresh.

By understanding these processes better, we can convert coffee cherries on the tree to export green bean better, quicker and to a much higher liquoring quality than ever before. In addition, we can not only use all the waste products from this industry to provide all the energy required for processing but also provide extra cash flow during the off season.

Coffee Wastes:

The microbiological view point can also help us to treat our coffee wastes in new and innovative processes. For over a 1000 years now, the coffee industry has stayed with historical traditional ways which have looked only at producing green bean for export and treating the rest as discardable waste! What the Coffee Industry in the Third World needs is additional sources of income and off season cash flow from coffee byproducts which up to now have been virtually ignored. Let us just remind ourselves, that if we go along with the traditional origins of coffee as a drink, then we have to remember that what Kaldi the goat herd passed onto the Abbot who wanted to keep his Monks awake, was all about the coffee cherry, not just the beans inside. (Q.V. The Great Millennial Mistake). Because it is only the beans that our ancestors knew how to preserve for export, the rest has been thrown away. For every tonne of green bean prepared for export, the local country side and its waterways have to reabsorb around three tonnes of wet fruit pulp, 150kgs of dry hulls or husks and up to 6 tonnes of high BOD heavily polluted water.

Coffee Waste Waters:

The first thing to do is to minimize processing water usage as much as possible by intensive recycling. Q.V.Chapter 1. This will also reduce coffee fermentation time to 6- 8 hours by not only raising the temperature of the water but also by increasing its level of fermentable sugars and enzymes, to feed those ravenous bacteria that do the job for us, and can do it a lot quicker than we may think!. The quicker it is processed the heavier is the resultant green bean! It will also greatly improve the colour of the dried parchment in the centre cut area, by fermenting or digesting out mucilage in those crevices that mechanical or semi washed processes can not get at. The biggest advantage however, is reduction in factory size. When each daily batch of cherry can be treated in less than 24 hours, that is, before the next days batch comes in, one only needs a third of the usual tankage and working space.

Of particular interest here is the way that East African small holders are using PVC

plastic water tanks as vertical fermenting tanks. This not only saves a mass of concrete, but the Bank Manager is also a lot happier to loan money on a portable factory that he can repossess and sell off to someone else, if payment is defaulted.

After about 3-4 hours of pulping, or when starting on a new receiving tank, the very dark batch of syrupy processing water should be discarded and pulping started off afresh with a new batch of clean water. That clean water recycled several times will soon be loaded with the right kinds of bacteria, and the sugars to feed them, from the surface of the cherries themselves. Cherry that has been picked for several hours, kept in a bag or in bulk and allowed to heat up, will be a seething mass of micro-organisms of all kinds working on the released sticky fruit juices. The majority of those bacteria will end up in the next discarded batch of process water, and continue to ferment the mucilage solubles right through to 'short chain volatile fatty acids', i.e. scvfa's. That is what biogas is made from.

Biogas from Waste Water:

All waste water should be collected in an open 'acid' pond, large enough to hold all of one day's waste water production. It should preferably be elongated, so that passage from one end to the other gives a set time of residence, usually 12-20 hours, depending on ambient conditions, and factory throughput. The naturally acidified effluent can be continuously taken out of the other end of the pond at the same rate as it enters. During that time, aided by about 2% of feedback, from the output end of the pond back to the input, all the mucilage, be it biologically or mechanically, retted or removed, is broken down to short chain oligosaccharides which cannot be digested any further. (Q.V. Soluble Dietary Fibre, and "The Great millennial Mistake") However, as the sugars are fermented down to alcohol and then vinegar, the acidity or pH drops to 3.8 and that will throw all the mucilage/pectins out of solution to float on the surface as an orange yellow scum, which rapidly goes black and solid on exposure to air. These solids should be raked off the surface of the acid pond as required, and added back into the cherry pulp solids for compost production.

From the far end of the acid pond, one can take out a clear yellow solution of scvfa's or 'vinegar'. This acid solution should now from time to time be pumped up through a bed of around one metre deep of 5-10mm limestone or marble chips in the bottom of an open trough. This will neutralize the acids to mainly acetate salts and raise the pH from 3.8 back up to 6.1. The CO^2 foam so formed will float out more precipitates, principally dark coloured tannins and polyphenolics. These can be raked off the surface of the trough. Evolution of carbon dioxide, CO^2, at this point enables the later production of a highly methane enriched biogas with only half of the usual level of inert CO^2 . Some Biogas Experts will also want to know where the hydrogen goes, which is usually also evolved at this point, because it should be contained and converted back into more methane. However, the reaction in the acid pond is more akin to the classical production of silage or vinegar, rather than 'acetogenesis' , which runs in parallel to methanogenesis, under more highly anaerobic conditions.

Food or Energy:

The clear nearly neutral acetate solution can then be either passed through a UASB or EGSB digester to make Biogas, or, dripped over a suspended curtain as in the aerobic 'Fungi Gulp" process to make Single Cell Protein for animal feedstuff. The Biogas production levels depend very much on the amount of original recycling and concentration, but a good ball park figure is around 3-5 litres of gas per litre of strong acetate solution. Do also note that the 'Renertech' UASB/EGSB sludge blanket is different to the usual kind in that it has a lot fewer acetogenic bacteria, and lots more

methanogenic ones. It also produces methane under more acid conditions. The original batch of this kind of sludge took a long period of enrichment processing to develop, but supplies of seed sludge can be made available to short circuit the enrichment process for those in a hurry. http://www.coffee.20m.com/CoffeeWasteWater.pdf

The Biogas produced can be best be used by running an engine on it to generate electricity, and all the lower grade waste heat from the engine cooling and exhaust can still be used for drying coffee as before. The engine, should preferably be a diesel dual fuel model, although ex petrol models can also be used, not only for biogas but also for burning producer gas from coffee husk, as outlined below.

Passage through the biogas digester will reduce the BOD by over 80%, but what remains contains remnants of the indigestible but pH sensitive fruit colour compounds, which as the acidity falls suddenly reappear as the familiar deep green/black colouring in the water that indicates the presence of a coffee factory for kilometers down stream on even quite large rivers. At this stage, all that can be said is that this colour, mainly anthocyanins from the red ripe cherry skins, ie. the red side of 'litmus' paper, and a precursor of the brown colour of swamp water, is harmless to fish, and intensive research is going on in the wine and olive oil industries, who have a lot more money than does the 3rd World coffee industry, to enhance present methods of fruit colour removal, as noted below.

Tertiary cleanup of Coffee waters:

By far the best thing to do with biogas digester effluent is to irrigate ones coffee with it. Biogas production is basically farming the sunshine for energy, and all the fertilizer components that came out of the soil, and are not exported with the green bean, come back to earth with the effluent waters. However, that utilization is not always possible, especially from large central factories.

When irrigation is not [possible, the neutral effluent water should be discharged into an artificial wetlands created by growing hollow stemmed water plants in a series of shallow ponds. Reeds and rushes can grow in highly anaerobic water because they pump enough oxygen back down through those hollow stems to keep their roots alive, along with the adherent symbiotic bacteria, the bugs that can start changing the black coffee water into brown swamp water, and begin the process of re-oxygenation.

The origin of the black colour that creates problems downstream from every coffee factory is not so much the red colour on the skin of the cherry as the colour in the fruit pulp. In slightly acid conditions it is yellow, but like the old litmus paper, change the acid to alkaline and it goes a reversible dark greenish black. However, let it get oxidized or aerated, and like the red skin colour it condenses into the familiar brown colour of rotting cherries and of swamp water. And that in time comes out of solution to end up as humus. None of these changes are harmful to fish and other water life, but they are most unsightly.

In areas where water hyacinth is available and legal, the reed pond can be supplemented with an additional smaller but deeper pond of water hyacinth which will create the most effective biological tertiary filter system known to 'mankind'! Instead of putting out water with a dull leaden coloured surface, due to a remaining high bacterial count, that wonderful filter of filamentous hyacinth roots, and their attendant microorganisms, are what can 'polish' (fine filter) the water to make it really sparkle in the sunshine once again. Do note however that water hyacinth does not like anaerobic water, nor salts in solution, so that first large pond, or ponds, full of reeds and rushes, is a vital part of the system. http://www.coffee.20m.com/RenerTechWWSystem.pdf

Coffee Pulp Solids to Silage:

A major instigation for the writing of these articles, is the attempt to educate coffee management to the possibilities of not only reducing costs, but also creating additional income by developing off season byproducts along with the seasonal production of green bean. Coffee pulp is really a very versatile substance, but the presence of caffeine and toxic tannins, has up to now been seen as a negative factor making it unusable as an animal feedstuff. Only in the last few years, since Rous and de-Menezes (Refs) has it been discovered how to convert it into animal feed ensilage. The ensiling process is done in such a way that digests out the alkaloids and tannin anti-nutritionals by using them as a source of nitrogen for protein synthesis by the bacteria concerned, usually lactobacillus species and Lactobacillus plantarum in particular. By a dewatering of the pulp, and packing it into plastic liners within stronger woven white plastic bags for smallholders, or FIBCs, i.e. one tonne flexible bulk containers for larger factories, within 4-6 months an excellent feedstuff suitable for small holders with one or two cows or large cattle feedlots is achievable, bringing an extra cash flow during the off season period. Do not add any nitrogenous material to the pulp, as the bacteria have to be kept hungry enough to make them attack the caffeine and break it down for its nitrogen content.

Mushrooms:

In contrast to the larger scale operations required for waste water treatment, coffee pulp can be handled on the small scale family level operation with ease. Fermented and partially dried, pulp can also be used as a substrate for growing exotic mushrooms. Of particular interest is the remixing of hulls and pulp to fast grow Shiitake, Linchi, Ganoderma and other specialist mushrooms that traditionally take years to grow on fresh billets of oak wood. All of these mushrooms when specially dried are greatly valued in Asia as 'old age' and 'rejuvenation' remedies. For those areas that dry process their coffee, more particularly Robusta coffee, what comes out of the hulling machine is not hulls but husk! Husk is a combination of hulls and dried pulp in an ideal configuration for growing mushrooms without the need for special blending.

Even quicker, in 3-5 weeks, is the production of Pleurotus or Oyster mushrooms which normally grow on old rotting trees in the bush. In areas where mushrooms are a prized food delicacy, smallholder coffee growers can bring in a significant cash flow from their local markets. All that is required are plastic shopping bags, two cookers made from a cut down oil drum, strong hands to squeeze out the water, and a quiet corner of their house or a shed. Propagation from local mushrooms found in the bush is possible, but if the local Agriculture Depts. do make mushroom spawn available that is usually grown on rice or wheat grains, then that is indeed a lot easier. Seminars to teach how this can be done, should be a priority for National Coffee Administrations, to train and supply Demonstrators/Teachers in every district.

Coffee Hulls:

Hulls are practically pure lignocellulose and have no fertilizer value at all. Yes, we all know how to get rid of the mountains of husk outside our dry factories, we burn it in crude furnaces to finish dry our coffee parchment. If most of the parchment is partially sun dried for quality reasons then, as in the East African states, even with today's crude single pass hot air driers, it is still possible to have a surplus of fuel after a finish drying operation. What more do we want to know? 'Ignorance is Bliss!'

What we could do is burn the hulls in a gas producer, and then run an engine on the 'producer gas', like we did with cars in the second world war, to produce electricity. Once

again as with biogas, the waste heat from the gas producer and the engine can be used to heat a clean air stream, and that can still be used to dry even more coffee than before. However, there are many coffee producing countries in much wetter climate areas where even a small percentage of sun drying is not always possible. Then every kilo of dry coffee hulls produced, and every percentage point of efficiency in burning it is vital! Can it be repeated again. It IS possible to dry ones coffee from its own hulls!

Countercurrent Drying of Coffee:

The modern grain drying industry in Europe and the USA has developed techniques of using every drop of useable heat by passing the hot air and the grain in opposite directions. As already mentioned, old fashioned single pass type flat bed and rotary dryers were developed 150 years ago to finish dry coffee in East Africa, where most of the work was done out in the open air by the sun, efficiency was not a problem and there was literally hulls ie.fuel to burn everywhere.

The problem with using some of these modern and more efficient grain dryers within the coffee industry, is that grain only needs the final 5-10% moisture removed after combine harvesting dry grain straight from the field. Grain this dry is free flowing. In contrast, coffee goes into the (first) drier dripping wet at 55% moisture, and needs 43% of that moisture removed. So much moisture removal, particularly with poor washing leaving residual mucilage, causes sticking and bridging of the coffee, which will not flow through the contorted pathways of the usual type of grain dryer, and sticks up in the machinery. It is usual therefore to 'skin dry' coffee in a flat bed dryer, where stickiness is not a problem, and once the parchment is skin dry then, if the weather is O.K., the parchment can be put out in the sun for bleaching and further drying with minimal chance of mould damage when the coffee is covered at night. Then the high speed, but oh so hard to accurately control, rotary dryer will do the finish operation. That means the coffee is handled three times, or four if one includes a spell in a conditioning bin to accurately adjust for final moisture content. It is in this area that a lot of processing costs can be minimized when prices are low!

If the coffee is very well fermented, washed and soaked, as outlined above, then most of the stickiness is alleviated, and drying in one operation can be attempted. It must be stressed again however, that partial sun drying, particularly in the early stages, is very important for final liquoring quality, and therefore multiple handling in the drying process is usual. Nevertheless, during times of bad weather it is essential to have efficient cost effective machinery that can cope with sopping wet parchment if required and take it right through to < 12% moisture in the most efficient and cost effective measure possible. .

If a lot of mechanical drying is required, and the Sheltered Mountain valleys of Vietnam and of Papua New Guinea are two cases of personal experience, heat efficiency is vital.: The use of countercurrent drying methods and equipment of modern design will ensure that drained wet parchment can be not only be totally dried with just the same amount of dried husk that would come from that same amount of wet coffee, but it can also provide a substantial reduction in electricity costs, the more so if one has to generate their own electricity from diesel fuel.

Overly rapid heat transfer:

The major problem with single pass flat bed dryers, such as the 'Wilkinson' ie.Asaro drier, is that the air is far too hot in the first instance, and unless the wet parchment coffee is vigorously stirred then the bottom half of the bed is dried far too quickly and parchment is cracking, before the top is even half warm. In contrast, a counter current operation means that there is no great difference in relative humidity between the stream of air and the coffee that it is passing through at any and every point of the transfer. Therefore all the problems caused by overly rapid drying, cracking

parchment, case hardening of green bean, micro cracking , and release of oil causing premature aging of green bean can all be alleviated. (Q.V. Chapter 3.) There now a few models of grain dryer which do seem to have all the attributes that would allow them to be also used for coffee, and at a very reasonable price. Even though those all important field trials on this kind of machinery have yet to be done with coffee, it is nevertheless confidently predicted that these new styles of drying machinery will ultimately come into use with coffee in wet climates.

HYPERLINK http://www.drzewicz.home.pl is a good one, especially the M850 model. Which at last check was costing around US$18,000-00 ex factory in Poland.
Search the internet also for "tapered sweep auger" drying silos. These can be made locally with differentials from old trucks, "Ugly American Style". Both of these machines blow hot air up underneath a very wide bed of grains in the base of a silo, which are continually moving down against the draft, with no possibility of bridging or hanging up on narrow channels or convoluted passageways. Both of these types are countercurrent. The hottest air only touches the driest parchment which is well past the point of shrinkage and surface damage. However, more importantly, they can start with wet parchment and dry it from Go to Wo, without extremes of temperature impacting coffee at its most vulnerable stages, and with only one handling operation, and no additional fuel beyond that from the process itself! That is not only more efficient and cost saving, it eliminates all the premature aging problems, and subsequent problems with mould germination just don't come into the picture!

Making Compost:

Coffee pulp solids contain only one fifth of the original nutrients taken out of the soil. Four fifths are lost from the land for ever, by export of the green bean. Therefore, although it is a good source of humus and organic soil carbon , it is not an answer in itself to make a complete fertilizer, much as the 'Organic' gurus would like it to be. However, just piling pulp up in a heap and forgetting it for a couple of years is no way to get anything like the value that it does have. We are all familiar with the results of such neglect. A black crust 100mm deep over the pile, loads of small vinegar flies, and inside the bright pink highly acid sticky silage or sauerkraut, which goes brown the moment it is opened up and exposed to the air. Direct use of that acid material will sicken coffee roots unless it is opened up and exposed to air until it too has gone not just brown but intense black, when all the tannins and other polyphenolics have condensed into humus.

Just leaving heaps of pulp for such long periods allows most of the nutrients to drain away as a thick black liquid which is highly polluting should it get into any water ways because it contains most of the caffeine content of the original pulp. If coffee pulp is turned over every few days, as in conventional compost making, it will compost in three weeks into one fifth of the original volume and weight of a stable earthy smelling material which does not attract flies. Leave that to mature for a further three months under cover, and it will reduce further to become a very nice dry finely particulate earthy compost which is a good soil improver and conditioning agent but not a fertilizer in the real sense.

It is at the point where the pile begins to heat for the second time, after the first turnover, that the collapse of structure occurs with a massive release of black sticky liquid which contains most of the nutrients and is the real fertilizer material. This liquid should not be allowed to flow away, it should be collected and sold as a high value organic plant nutrition agent and pest deterrent, that's the caffeine of course, to give an extra source of cash flow.

The whole process can be speeded up even further and the production of liquid and alkaloid increased, by the addition of 0.05% of the wet weight of the pulp as urea, or better still DAP fertilizer. That fertilizer content will be recovered as technical 'organic'

nitrogen in the form of bacterial protein within both the liquid and the solid compost. Production of such 'boosted' compost should be a legitimate ploy for growing 'organic' coffee.

Carbon Credits:

Time will tell whether Carbon Emissions will become important, but if they do then it is at this point that they will become important for Coffee. As long as those heaps of coffee pulp remain acid and bright pink on the inside, with a black crust, then they will be totally preserved. However, if they are left out in the open then the rain will gradually leach out the acids and methane will be emitted from the narrow layer of brown material under the black crust causing the heaps to slowly subside. So, storage under cover or converting pulp wastes to compost or silage could well be a source of Carbon credits. This would be in addition to making the maximum of methane out of coffee waste waters etc. and then burning the methane to recyclable carbon dioxide.

Growing 'Organic' organic coffee:

More than 50% of the worlds coffee production is grown without imported fertilizers, pesticides or herbicides, and can be considered to be technically 'organic' in every way! However, the beans are small and liquor quality is poor. The 'Organic' fraternity want to label it as "Naturally grown" coffee, and keep their hard won "Organic" label for very good quality coffee that will sell through the high priced Specialty outlets, for a premium price. Good quality coffee requires 'Acidity' 'Body' and 'Flavour', and that requires big fat beans stuffed full of Proteins, Carbohydrates (ie.sugars), and Oils. All of those components come from photosynthetic sunshine products as well as soil nutrients. That requires hard deep green 'sun' leaves, rather than the pale green softer 'shade' leaves. So, advocating shade to minimize on fertilizer requirements is not really an easy option if you want a quality product.

It is my considered opinion that the only way to get even close to growing 'Organic' organic coffee is, in addition to careful use of coffee wastes, to plant low growing ground leguminous cover like wild or perennial peanut ie, Arachis pintoi, around the coffee trees, and to grow leguminous shade trees which are able to be heavily pollarded on a regular basis. The big secret however is in the management rather than the growth of this extra 'organic' material. The best shade tree is Casuarina, known in PNG as Yar! It fixes nitrogen, pulls more phosphates out of clay soils than most other species because of its VAM roots and is very easily pruned on a regular basis to become like a hedge or a series of fuzzy beanpoles. There is so much potential growing on, right under our very noses!

Wastes treatment is not really the place to go into details of the leguminous root nodule bacteria that create those nutrients, but they are still within the 'microbiological' umbrella, so let me comment further! Trees and plants are not silly, and they do not give away costly material like nitrogen at all easily. All the nitrogen fixed by root nodule bacteria go right back into those same roots and only those roots that have nurtured them. Furthermore, any foliage that is dropped naturally has had all the nutrients clawed back out of it before the trees will let it go! Autumn leaves are only the skeletons of their former selves. Its only when fresh green foliage full of nitrogenous proteins is cut from the source and spread under ones coffee as a mulch that any real transfer of fertilizer nutrients will occur. And, it is by cutting twice a year from the moment that it is a small plant, and only cutting green foliage, like when ones trims a hedge, that a tree will keep producing green regrowth all the way up its trunk. If you wait until the tree has got large branches and then chop those off, regrowth of lush foliage will not occur.

Everyone can tell stories of trying Arachis pintoi as ground cover and the coffee was

worse rather than better. Aggressive plants like Arachis can pull more fertilizer chemicals out of the soil than coffee ever could, and they will steal it all away from the lesser efficient coffee roots as well, and the coffee will suffer. So, they then have to be cut back themselves just as aggressively and used as mulch to transfer that fertilizer back across to the coffee. This is where a side swathing rotary mower will really cut labour costs as well as Arachis! (that's punny) The thicker the mulch from any source, that can be built up under ones coffee trees, the less is the competition from weeds, including its own seedlings and the Arachis itself. Also the greater the IPM protection from the bronze beetles and other predators that live in the mulch and gobble up cicada nymphs and discourage ants and greenscale. And the better the mulch, the better the coffee roots will function in a cool damp environment. The experience of overbearing dieback makes me say that the roots are the weakest point of a coffee tree, and keeping those root systems pumping is the main answer to growing high value coffee. And that includes the science of grafting with more vigorous rootstocks.

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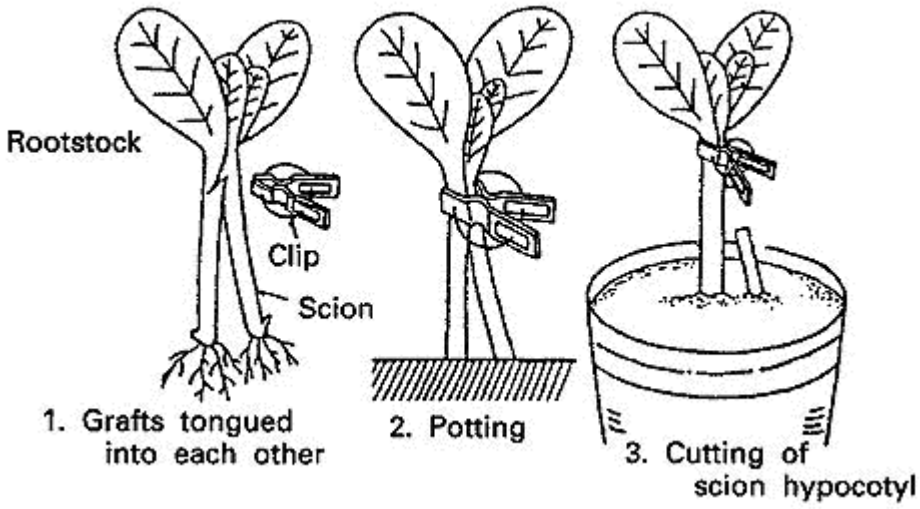
Post Script:

Boosting the Roots.

It is my considered opinion, probably negated by equally opposite opinions from others, that the weakest part of Arabica coffee trees are their root systems. 'Over bearing dieback' is not a disease, it is inability of the root systems to cope, with the increased load from an extra large crop, or, from reduction of fertiliser applications when times are hard, thus throwing extra strain on the roots. By the time that the leaves indicate a problem, the roots are already dead and attempts at recovery, by adding extra fertiliser etc., are futile. Any effort therefore to improve the rooting system must give an improvement for sustainable coffee production under poor soil conditions.

A lot of work has been done on grafting arabica onto robusta root stock, which does live up to its robust name in this regard, and is readily available in most areas. In Hawaii, the home of most grafting skills and technology, the favoured rootstock is liberica. And they also have some special varieties bred for this purpose.

For excessively wet conditions there is a hybrid root stock called Conabusta. (There are two Conabusta trees growing near the old swimming pool at Aiyura) The technique of grafting is not too difficult to learn, and in my opinion would be capable of being taught to those 'more motivated small holder farmers', who might be interested. For Plantation work it should be a 'Must!' It is much easier to work with seedlings, by potting a robusta and an arabica seedling together, and by 'in arch' or tongue grafting, much like grafted 'supertom' tomatoes.



By cutting the stem from the root stock, above the graft, rather than cutting the scion, below the graft, as illustrated, the final tree ends up with both the arabica and the robusta root systems, a double whammy. This is what they do with grafted tomato plants.

It is also possible to re work adult trees at recycling by stump grafting. However, the shoots for grafting in this way must be from suckers, or the tops of old trees, which possess 'apical dominance'. Grafting primary or secondary side branches into a vertical position provides most grotesque and disappointing results. This is why using seedlings as graft material gives a much better shaped tree, but is then subject to at least 2 seasons delay before fruiting, in order to obtain mature fruiting branches on the resultant structure.

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