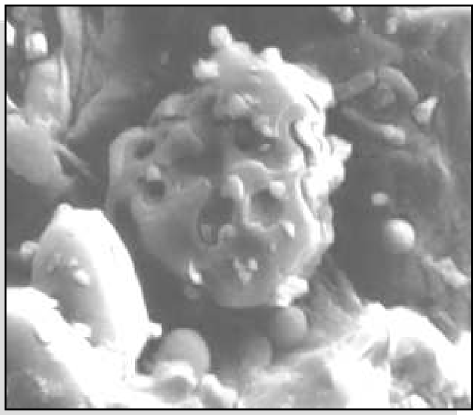
The Science of Malting and Brewing

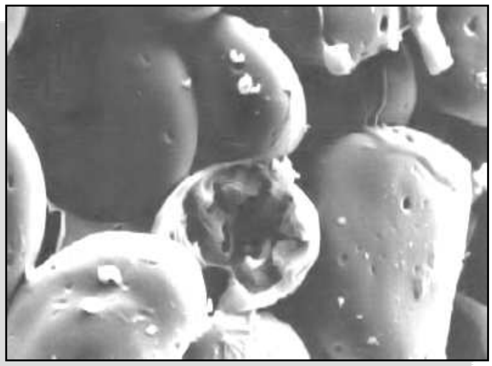
Based on a talk given as part of the Cambridge University Science Week, March 2008

It is widely recognised that the Egyptians most likely brewed the first beer, but just how much did they know about what was happening and what have we learned about the process in the past 3000 years or so? This was the subject of a talk presented to around 150 people in Cambridge as part of the special Cambridge University Science event that ran from March 10-20. A special beer had even been brewed for the night by Bruntingford Brewery.

Statuette of a Woman Preparing Beer", Cairo Museum ,Mastaba of Meresankh, (24th Century BC)

Early Egyptian brewing was thought to have arisen using bread as a source of starch and liquid drained from that kneading process was fermented sometimes with the addition of dates as an extra source of sugar. Models of women kneading bread (left) and sieving the extracted juice are found in excavations. Shards of broken vessels have been found in Egypt that contained beer. How do we know? One of the constituents of beer sometimes found in beer hazes (calcium oxalate) crystallises out onto the shards and has a characteristic diamond shape. Some of these crystals had starch granules attached along with tiny yeasts. Actually the size of the yeast tells us a lot – the tiny yeasts are generally found in the atmosphere and would naturally ferment a liquid derived from bread if left, especially in the heat of that area. But did the starch always come from bread or did they know how to malt cereals? A close examination of the starch granules from these old pots suggests that they did malt.





The pictures to the right are of starch granules. They are very small and about 50 of them laid end to end would be just 1mm long. But look carefully at the pictures – the starch has tiny holes (pits) and appears to have been scooped out to reveal the inner concentric ring structure of the starch. This process is due to enzyme action during malting that turns the starch into sugar ready for the plant to grow – to a maltster pitted grains indicates the malting process is our of control, wasting valuable starch – so yes the Egyptians do seem to have used malted cereal but not in a controlled way. Perhaps they left some grain to get wet and it started to malt naturally. Maybe they knew a little about the need to immerse the grain in water as some hieroglyphics can be interpreted.

Certainly the Egyptians didn't use barley for brewing but used what is more like a wheat – the Emmer grain (left) which looks like barley with its long awns. Piles of this grain that had started to malt and then stuck together have been co-excavated with beer jugs.

The beer itself was probably quite rough and not bittered – they called it Hek – for us the pun is obvious – 'what the heck is it' would be a likely outcry if we had to drink beer through a long straw and filter out the bits through our teeth!

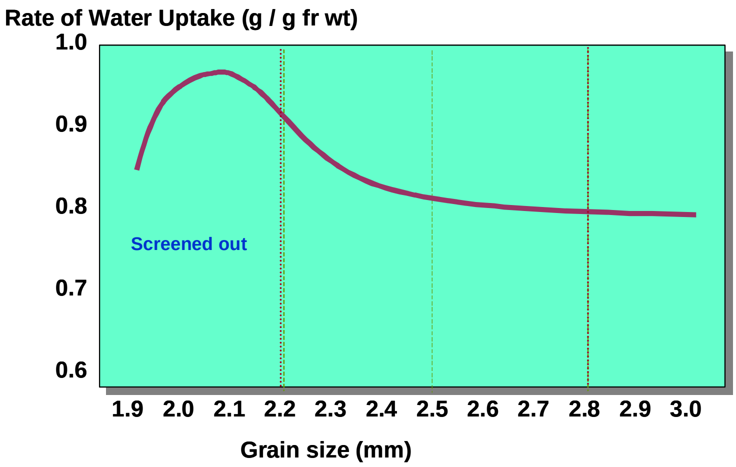
The Emmer plant grew to a height of 2m and would easily fall over (lodge) in the field and was likely very high in protein. That's already an area where great progress has been made in raw materials. Modern barley is just around 750cm tall, rarely lodges and has much lower protein content that makes it easier to germinate and mill after kilning.

Some years back Scottish and Newcastle managed to prove that beer could successfully be brewed from modern day emmer equivalent (spelt wheat) producing Sphinx beer (right). Using the improved processes in the brewhouse the final beer was clear (bright) and pleasant to drink.

Modern malting practice has of course moved strides ahead and even since the late 1950's malting times have tumbled from 20 days to 7 days from steep to kiln. There is plenty of good science behind this improvement. we can consider just a few.

One of the most important requirements for malting is to have a grain that is sufficiently hydrated after steeping that it has sufficient water to germinate and allow the free movement of enzymes that will remove the unwanted parts of the grain that make it hard and difficult to convert to a sugar solution for brewing.

Various factors have been found to influence what seems like a very ordinary process

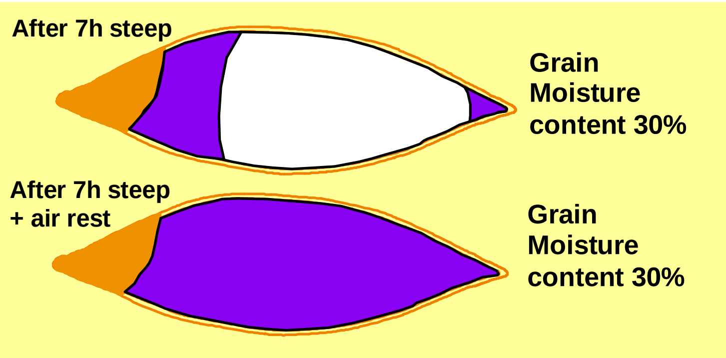


Grain size: What is the effect of grain size on water uptake and distribution?

The graph (right) shows that water uptake is affected by grain size and that it is most even between 2.5 and 2.8mm and most variable below 2.2mm. It's no coincidence that we screen out grains below 2.2mm and favour barley varieties with grain sizes between 2.5-2.8mm. There are other reasons such as better starch:protein ratio, but size is so important in steeping that it is vital to screen even on this basis alone.

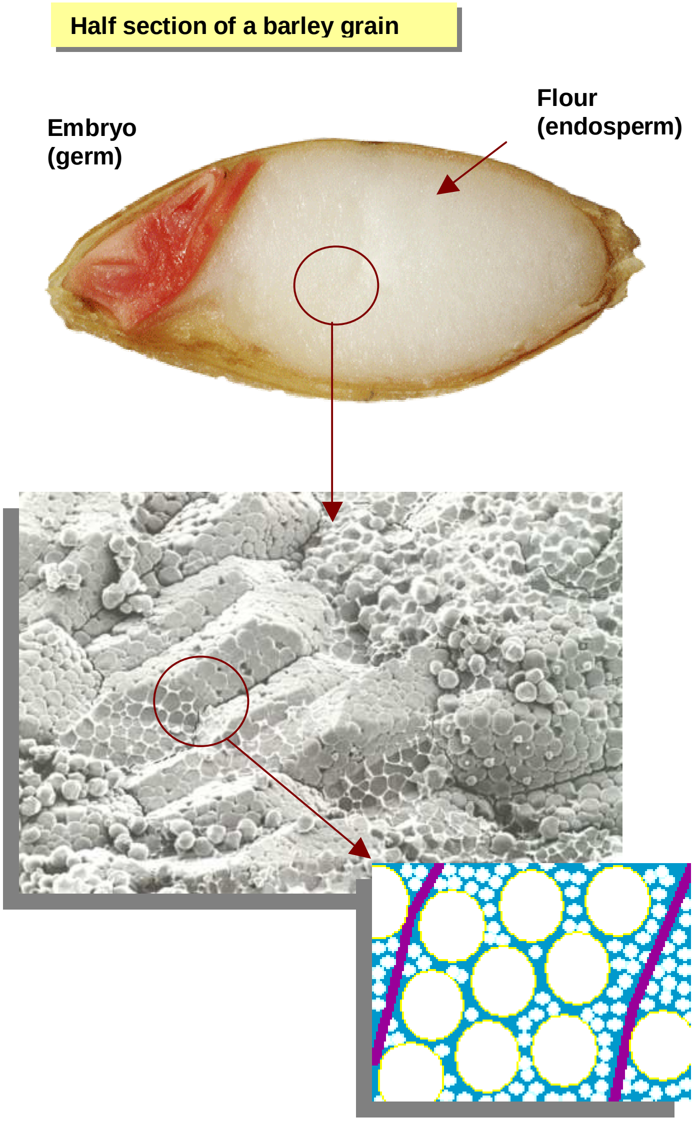
Grain structure is also an important consideration. It is now understood that water only gets into the barley grain through the embryo. Water is then distributed throughout the floury endosperm. This distribution takes place more quickly if the grain is drained of water, hence wet and air-rest (drained) periods during steeping are employed.

On the right this water distribution can be visualised by staining the wet starch with iodine vapour. Without the air rest it would take much longer for the grain to become hydrated.



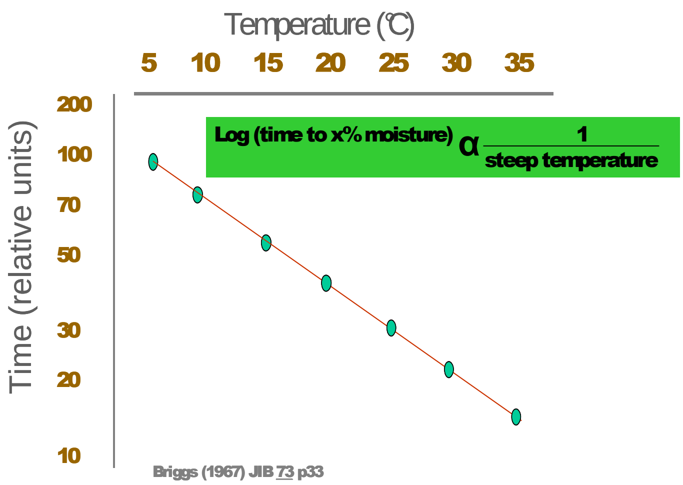
Purple areas reveal where the starch is hydrated. It's the usual starch/iodine reaction except here the starch is wet and the iodine is introduced as iodine vapour (gas) inside a petri dish. Although the moisture content is the same in both grains, after an air rest the water has migrated throughout the floury endosperm.

We also now understand the impact of the physical structure of the grain on water movement. If the grain cannot become hydrated it cannot generate the hormones that set off the production of enzymes that breakdown those parts of the grain that we don't want or that would cause problems in brewing or food production. The scanning electron micrograph (right) of the inside of a barley grain shows that the starch is tightly packed. It is in fact held together in cells, the wall of which are made of beta glucan. Now although beta glucan is good for your health in some forms it makes a very viscous paste during brewing and causes slow production times and is one cause of haze in beer.



Although you can't see the cell walls in the picture you can see where they were because the starch is shaped into angular blocks. The position of the walls is demonstrated in the inset diagram. Where the starch granules have fallen out of the section a web like matrix is left behind. This is protein and some protein is useful to generate a good head on the beer. There are also two sizes of starch granules in barley. We aim to keep the large ones and let the grain grow by using up the starch in the small granules – Why? Because during mashing the small starch granules only partially gelatinise whilst the large ones completely gelatinise and are converted to sugar. The partially gelatinised small granules make a very viscous wort which can be difficult to filter.

Temperature of the water is also very important. A very quick look at the graph on the right shows that the higher the temperature the less time it takes for water to get into the grain.

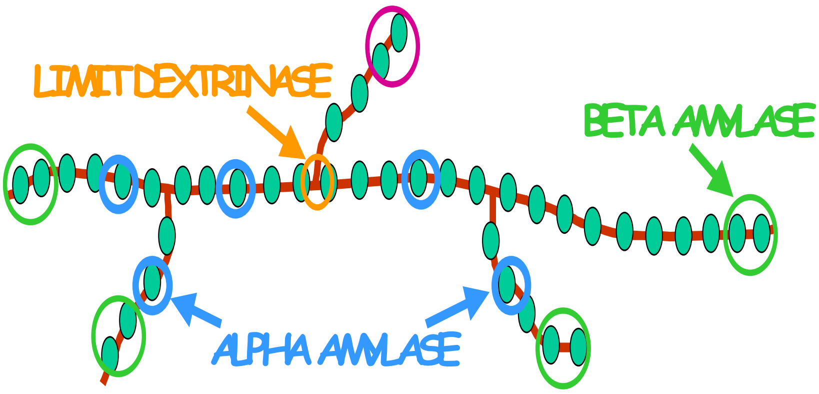


A very real effect of this has been seen at Stowmarket. The new line to use cooling water that we would normally put back into the river has now allowed us to heat up the steep water that comes out of the borehole. Normally this water is about 11°C. We heat it to about 18°C. If we didn't you can judge from the graph that it would take about twice as long to get the grain hydrated and slow production down dramatically. Using the cooling water from MMI we now need less energy to heat up the steep water.

Returning now to enzymes. The barley grain starts to produce the enzymes it needs to convert starch to sugar an protein to amino acids as soon as it begins to grow. In malting we control this process so that only the parts of the grain that make it unsuitable for food processing or brewing are removed. This is achieved by a cascade of natural enzymes produced by the grain.

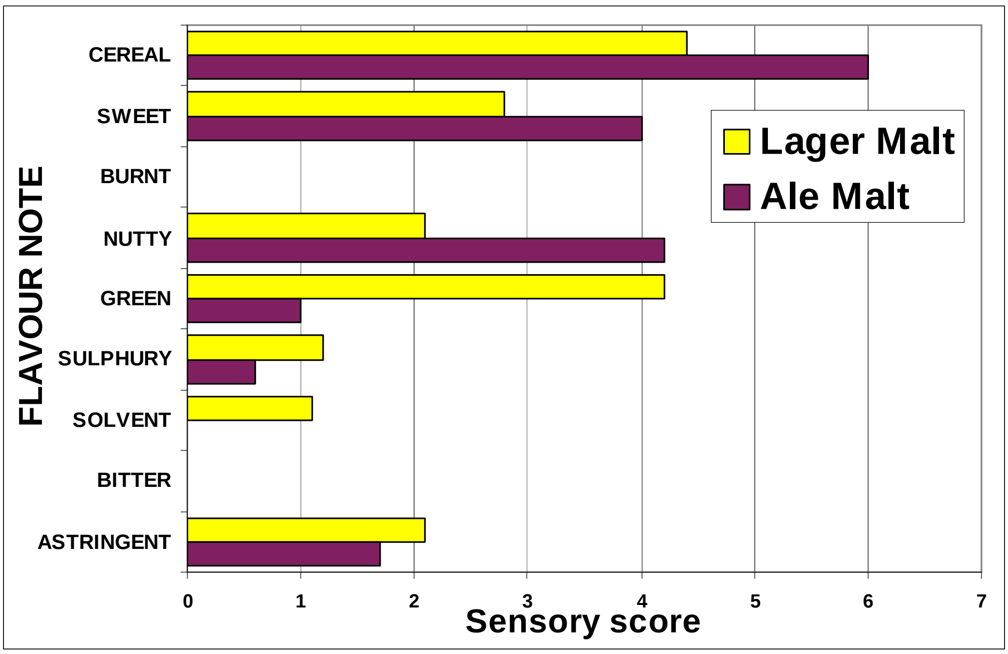
A chemical signal (hormone) is made by the embryo and moves to a very specialised layer of cells on the outside of the barley grain. This layer of cells is called the aleurone. Barley is much better than other cereals because it has 3 layers of these cells , wheat and the orginal emmer have only one layer, so their ability to produce enzymes is less than barley.

The enzymes are very specific and one set solubilise the material and another set then degrade the component. Removed almost entirely is the beta glucan in the cell walls, the small starch granules and a little protein. Some protein is changed in nature to be more soluble and foam positive to ensure a good head on your beer or that sufficient amino acids are available for yeast nutrition during fermentation.



The starch-degrading enzymes are particularly important. On the left you can see a stylised starch molecule. Starch consists of a string of glucose molecules (the green ovals). To make the sugars need for growth a number of enzymes chop off the glucose units. Some can chop in the middle of the chain (alpha amylase), others chomp away only from an end (beta amylase). The molecule is also branched and at this branch point yet another enzyme (limit dextrinase) is required to fully convert the starch.

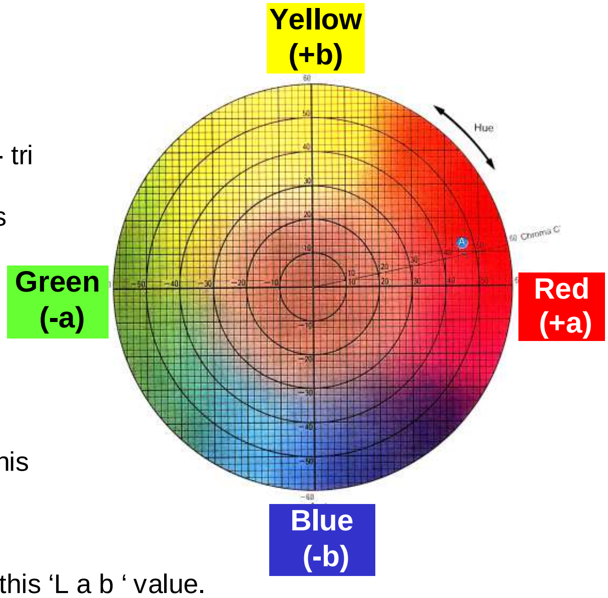
Armed with this knowledge some brewers are able to make a low alcohol beer. The enzymes beta amylase and limit dextrinase are very sensitive to heat. Mashing at high temperatures right from the start of brewing inactivates them and the starch can't then be broken down as well, less sugars are produced and hence less alcohol. Clever eh!



During malting a series of sugars and amino acids are produced that generate both colour and flavour. In the kiln it is possible to effectively cook the grain before drying it to allow the sugars and amino acids to combine together to make some interesting flavours and colour, or the malt can be dried out quickly at lower temperatures producing little colour. This is an area which has recently gained a much higher profile. You'll no doubt be familiar with the many esoteric descriptors applied to wine or beer tasting. We can now make a similar profile for malt, although the terms used are rather simpler to understand. On the right is a profile of a malt that has been kilned lightly (lager malt) and one kilned at much higher temperatures (ale malt). The flavour terms are hopefully self explanatory with the exception of 'green'. This means green and uncooked and is therefore much higher in a lager malt, as is the sulphury note, both being positive flavour attributes in a lager, whereas ales require much higher cereal malty, sweet and nutty flavours. The malts are finely ground, mixed with water and sniffed and eaten to determine the flavour profile.

Having generated colour in the kiln it might seem like a very simple matter to describe the malt colour, the beer colour or the baked goods colour. Not so! Colour has for years been assessed by making an extract of the malt and, because it's a brownish yellow colour, comparing it against brownish yellow disks of varying shades (see left). However, this is no longer good enough for some applications and I can vividly remember about 12 years back if I could recommend a malt that would make a Virgin red beer (virgin as in Richard Branson's company name).

To achieve this level of sophistication a better colour measurement method was required that would describe all the various colour components of the product in the same way the human eye perceives them. The method is termed tristimulus - tri because there are three components: red, green, blue, the primary light colours. Measuring the level of these three colours allows us to describe every colour possible.

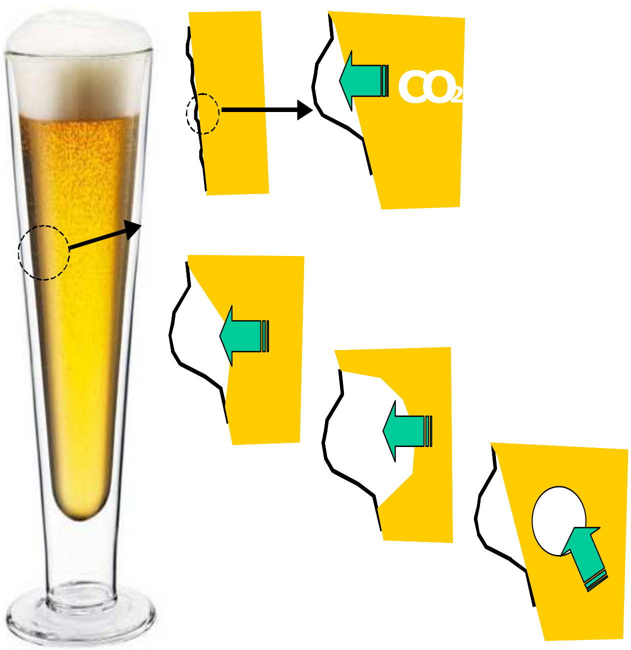


To the right a 2D graph is shown of how colour can be described. Actually all colours possible would require a spherical graph. This graph shows how a colour can now be described: either as the amount of red, green and blue or as a coordinate on a graph: the 'a' value representing the amount of green/red, the 'b' value the amount of yellow blue, and then a this value 'L' which represents the lightness of that colour combination.

We now have customers who specify both ordinary colour and this 'L a b ' value.

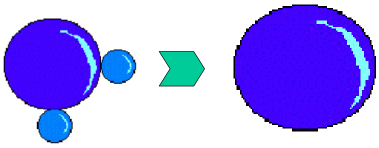
Finally in terms of the increased knowledge we have of beer presentation I turn to beer foam. Have you ever wondered why beer (or any carbonated drink) makes a foam and what makes it collapse. I hope so, so here goes!

On the right you see a beer with a good head and lots of bubbles moving up through the beer (called beading). Bubbles are generated at the interface between the glass and the beer because no glass surface is perfectly flat. Due to surface tension the beer doesn't fill these microscopic holes. The gas (carbon dioxide) in the beer begins to migrate into the hole and as the pressure increases it forces the beer away from the wall. Eventually a bubble forms. Gas continues to move into the bubble as it rise through the beer, so it gets bigger as it moves upwards. If your glass surface is dirty or the beer has insufficient gas it will not make bubbles.



Once the bubble is in the foam head there are a number of ways the foam can collapse as illustrated in the diagram to the right.

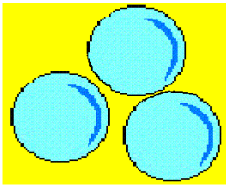
This also shows that the old beer steins had a real purpose and were not just designed to get in your way as you drink: The lid maintains a gas pressure above the foam that slows down the movement of gas between bubbles and preserves the head for longer!



DISPROPORTIONATION

Small bubble: higher pressure

Gas passes into larger bubble



COALESCENCE:

As beer drains from between bubbles the walls become thin and

Foam Head collapses

Beer then has moved on in leaps and bounds from the early Egyptians using a combination of knowledge and fortuity to generate a product enjoyed by many. Indeed they had a hierarchy of beer consumption. Temple workers received 2 pints a day and dignatories 10 pints. However, they drank not for the alcohol hit but because they believed it guarded against colds, coughs, shortness of breath and indigestion. One of the main results of over consumption wa learned early on and many hieroglypics show guests being sick after a banquet!

Although beer is a fantastically diverse, healthy and enjoyable drink when consumed sensibly, we are plagued by the impact of binge drinking which gives the product a bad name. Maybe this shouldn't surprise us because it's not new. An ancient Egyptian book entitled the Wisdom of Ani recognised the pitfalls of over consumption:

> **The Wisdom of Ani:**
> **"Take not upon thyself to drink a jug of beer ... or your companions may repeat words which may have gone out of your mouth, without your being aware of having uttered them"**

Nigel Davies, April 2008