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Flavour stability in home brewing

Introduction

Famous painter Edgar Degas once declared the frame to be 'the pimp of the painting'. If he were a brewer, he might have made a similar statement about beer freshness; as it is exactly that what makes a good beer pop.

Sadly enough, for both brewers and consumers alike, **beer is unresistant to** the tooth of **time**. Noticeable staling can already occur 2-3 months from packaging when stored at room temperature. As beer starts to fade, it loses precious aromas and pleasant (hop) bitterness, all while developing unpalatable or harsh off-flavours. The question is: does this phenomenon really concern a home brewer?

Well actually, yes. A home brew will suffer the same fate as any commercially brewed beer, probably even quicker. Not much oxidation is needed to turn a price-winning home brew into a just "okay" beer. Luckily, when keeping certain codes of conduct in mind, it is more than manageable to keep your beers from tasting like wet cardboard, paper, cherry, honey, leather, horse stable, cat urine, ...

The following article will delve into the 'what' and 'how' of brewing long(er)-lasting beers, with information roughly ordered from 'easily implementable' to 'advanced tinkering'.

(TL;DR: Check the **summary table** at the end)

High relevance and easy to do

Limiting storage time (drink it fresh)

There is always the option of not giving beer the time to turn stale. Although this is more a bypassing-the-problem than a solution, it works. So always label your beers properly with a 'packaged on' date and drink the older beers first (**FIFO** method: First-In, First-Out). Make the fact that home brewers deal with small batch sizes work in your favour and keep in mind that some beer styles are more susceptible to ageing than others (e.g. hoppy beers, pilsners).

Storing dark and cold

From all the things a brewer can do to maintain freshness, this is top of the list. Firstly: Protect your beer from any damaging (ultraviolet AND visible) **light**; mainly the sun or fluorescent lamps. Storing beer in the dark will prevent it from getting "skunked" or "light-struck", terms used for describing beer that tastes like skunk spray—as literally the same molecule (3-methyl-2-butene-1-thiol, a sulphur compound) is being formed by photodecomposition of hop alpha-acids. Cans and kegs will keep light out perfectly; brown bottles less so—albeit better than green or clear containers—so best to preventively keep them covered during storage.

Secondly: Keep your beer **cold**! This is, by far, the biggest component. Those familiar with the Arrhenius equation will tell you that a temperature rise (or drop) of 10 °C roughly equates to a doubling (or halving) of the reaction rate. Here is what this means for your beer:

Storage temperature (°C)	Staling rate compared to room temp. storage	Estimated time before staling occurs	Examples
0	¼ x	> 1 year	Fridge, bucket with ice
10	½ x	4-6 months	Fridge, cellar
20 (room temp.)	-	2-3 months	Living room, indoors
30	2 x	1-1.5 months	Warm room
40	4 x	2-3 weeks	Garage, attic, car trunk (sunny)
60	16 x	<< 3 days	Garage, attic, trunk (hot day)

Due to the difference in production size, cooled storage/transport is an area where home brewers have an edge on the 'big guys'. However, not every home brewer possesses the luxury of having lots of refrigerated space.

Limiting oxygen downstream

Although it is hard to tell for sure, it can be reasonably assumed that **limiting oxygen** downstream is more relevant/significant than limiting O_2 upstream. Which is why oxygen entry on the cold side (after fermentation) is likely the second biggest detractor of flavour stability that home brewers face after warm storage.

Prevent any unnecessary **transferring** of your finished beer, and when required, do it gently (avoid splashing/turbulence/aeration) and push with CO_2 where possible. It's best to **purge** any container (such as bottles, carboys, kegs, etc.) multiple times with CO_2 or N_2 before filling and to fill from the bottom up. Hoses and pumps can also be purged, or better, prefilled with deaerated water to expel oxygen. When bottling, always '**cap on foam**' (by agitating the bottle slightly), so that headspace oxygen is minimized. That said, bottling by hand unfortunately often results in very high oxygen pickup, which is the reason why beers at home brew contests frequently suffer from staling.

Bottle caps are another unavoidable detractor from beer flavour stability when bottling, but not all caps are created equal. Pry-offs are better than twist-offs, which is why, for example, Sierra Nevada changed their twist-off caps to pry-offs in 2007. The liner material of the cap also matters, as some allow for more oxygen ingress than others. Then there are also specialized oxygen-scavenging caps, specially designed to combat this issue. If you want to go all-in, you can even dip the capped end of the bottle in melted wax or paraffin (perfect for e.g. barley wines); and buying a ‘dissolved oxygen’ meter can be a very valuable tool in the brewhouse (albeit expensive).

Kegged beer is less prone to oxidative ageing, because the headspace-to-beer volume ratio (initially) is much lower compared to a bottle. **Canned** beer has the advantage of having absolutely no oxygen ingress after sealing. Regardless of the container type, always store a beer upright and keep **vibration/transportation** to a minimum. This way, the beer has less chance/surface to interact with the oxygen-containing headspace, thus slowing down oxidation.

Side note: Be aware that commercially available carbon dioxide (CO_2) is never pure. While even the purest commercially available grade (99.9 %) may seem “practically pure”, it is not. Force carbonation of the beer will result in a certain amount of O_2 getting dissolved; enough to elicit staling. To avoid this problem, brewers can choose to carbonate their beer naturally—via e.g. spunding/bunging—with 100 % oxygen-free yeast-produced CO_2.

Using healthy, vigorous yeast

Never forget that it is the yeast that makes beer, the brewer “just” makes wort. In other words: pick the proper yeast and treat it like a queen. It can make the difference between an amazing beer and unpalatable swill.

More than just creating beer, the yeast also does a great job in **cleaning up** aldehydes (off-flavour contributors) **and scavenging** detrimental transition metals (see later). Researchers were even able to chiefly remove the stale flavour from aged beer by adding fresh yeast to it. Aside from these rectifications, it will also help the beer to stay fresh over time by producing **sulphur dioxide** (SO_2, a potent antioxidant and carbonyl binder) during fermentation and **lowering** the level of free amino acids and **dissolved oxygen**.

So, a healthy yeast and **vigorous fermentation** are important for flavour stability. To improve yeast performance, you may supply extra zinc and oxygenate the pitching wort (but only when cold!), and that should be the only point during the brewing process where oxygen is deliberately introduced. Keep in mind that different yeast strains have different oxygen demands. When fermentation is prematurely halting or “stuck”, it’s even worth risking oxidation by aerating the semi-fermented beer to help restart the yeast. Of course, it is better to prevent it altogether by fermenting at the **recommended temperature**—preferably on the lower side—and **pitching enough** fresh yeast (make a yeast starter or, if using dry yeast, rehydrate before pitching).

Limiting heat load during brewing

As touched upon earlier, temperature is a huge driving force behind any chemical reaction, including those involved in the formation of **off-flavours** (Maillard and Strecker degradation reactions). Some of these created off-flavours are non-volatile and will migrate into the final beer, where they can lead to flavour deterioration. Additionally, more heat load equates to more free radicals and other reactive entities, which equates to **more oxidation** and further off-flavour formation (e.g. aldehydes).

It is important not to mash below 62 °C. More than limiting unnecessary heat load, starting the mash at 62 °C will make sure **lipoxygenase** (LOX) is largely inhibited, which benefits flavour stability greatly (LOX enzymatically oxidizes unsaturated fatty acids to E-2-nonenal, causing cardboard flavour). With the well-modified malt of today, there is no need to do any enzymatic steps under 62 °C—such as acid rest, ferulic acid rest and protein rest—and there can even be argued that multiple temperature steps, in general, are obsolete with the current quality of malt (as done in 'single infusion' mashing). Another way of limiting lipoxygenase activity is to use LOX-less barley malt.

Also **avoid excessively long boiling**. Do this by utilizing an energetic "rolling" boil, which will ensure all necessary boiling requirements are well met within the hour. A rolling boil also helps achieve higher clarity (clearer wort), greater hop utilization, lower levels of dimethyl sulphide (DMS), and a better hot break. It is best not to cover the boil; even though it might help speed up the heating process, it will hinder DMS and aldehyde removal.

Another possibility (albeit more challenging) is to utilize a soft "simmering" boil—or even just below the boiling point—and bubble an inert gas into the mash, to still ensure sufficient volatile removal. Heating by direct steam diffusion is yet another way to lower heat load and mash oxidation (lower shear forces). Always **cool** boiled wort **down** to pitching temperature as **quickly** as possible (to reduce excess heat load) and **remove** the **trub** (to avoid fatty acid excess).

High relevance but more challenging

Avoiding transition metals

Iron, copper and manganese **promote oxidative** (Fenton and Haber-Weiss) **reactions** in wort and beer; and thus, the formation of aged flavour compounds (such as cardboard, papery and cherry) and the decrease of wanted compounds associated with freshness (such as hop aromas and bitterness). They can also contribute to **haze formation** and **gushing**.

Prevent your mash/beer from picking up unnecessary traces of iron, copper and manganese. They can emanate from various sources: untreated water, Fe- or Cu-containing brewing equipment (certain kettles, pipes, pumps, buckets, tanks, filters, kegs, cans, crown caps), raw materials (malt, adjuncts, hops, yeast), process agents (kettle finings, stabilizers, filtration aids). While some sources will be **hard to control** or get rid of—such as the raw materials—others can be dealt with—e.g. the usage of iron-rich kieselguhr for beer filtration.

Luckily, a lot of the said transition metals (Fe, Cu, Mn) will drop out with the trub and hot break during mashing and boiling. Unfortunately, some of their damaging effects (e.g. formation of reactive oxygen species) will already have occurred by then, so "less is definitely more". Also, metal picked up after boiling will not drop out anymore—although some metal ions will be scavenged by the yeast during fermentation and drop out during conditioning. Be aware that dry hopping can introduce “high” amounts of manganese (and oxygen!).

It is possible to lower the ‘active’ transition metal content during brewing by adding **chelating agents/chelators**. Two examples of chelators that are successfully being employed in brewing are **tannic acid** (a gallotannin found in e.g. oak) and **ellagic acid** (a polyphenol found in e.g. pomegranate). They do this in two ways: Firstly, by forming large complexes with the transition metals present (i.a. iron). This inhibits the metal ion to partake in oxidative mechanisms. Secondly—because the formed metal-complexes are so large—by effectively lautering and/or filtering the metal ions out of the wort/beer, thus removing them completely out of the process. This tendency to form large complexes also makes tannic and ellagic acid suitable for beer clarification, behaving as clarifying/fining agents.

Another way to lower the amount of metals overall is to not acidify the mash. A **mash pH** of 5.2 will cause a much higher leaching-out of iron, manganese and copper (from the malt) into the wort as compared to a mash pH of 5.4-5.6. A higher mash pH will also promote enzymatic activity and allow for faster DMS removal.

Of low(er) relevance or controversial

Limiting oxygen upstream

There is zero disagreement on whether **oxygen will damage your brew**—it will; be it upstream (‘hot side’) or downstream (‘cold side’). It is the relevance of limiting oxygen upstream that still has some brewers—and scientists—debating. The “does hot side aeration matter?” forum discussions can get quite heated at times, which just shows the ambiguity of the topic.

Whether you believe it’s relevant or not, there is no excuse for splashing around hot wort or mash liquor. Apart from it being hazardous, **mash oxidation** will occur very rapidly at these high temperatures, ultimately compromising the final quality of the beer. **Hot side aeration** (HSA) may also cause a lot of other things:

- Darken the colour of the wort and final beer, because of polyphenol oxidation (which, in turn, will lower the antioxidative potential and, ultimately, the flavour stability)
- Promote enzymatic oxidation (by e.g. lipoxygenase)
- Make wort more cloudy
- Cause immediate or indirect flavour changes

Especially for beginning home brewers, the whole HSA-topic can get quite daunting. In the end, it all boils down to what the brewer wants to achieve, is technically able to realise and what she/he feels comfortable with. There is probably not much point in meticulously minimizing HSA if the downstream oxygen pickup is not yet optimized. But for a seasoned or advanced home brewer, ‘**low dissolved oxygen**’ (LODO) brewing can be an exciting way to give the beers an extra dimension.

Here are a few examples of how diminished hot side aeration can benefit the brewing process and the resulting beer:

- Less crosslinking of proteins through disulphide bridges (formed by mash oxidation of sulfhydryl containing proteins), which results in:
  - A faster and more complete lautering, because of increased beta-glucan breakdown
  - A higher attenuation limit, because of the more complete lautering, and because of less starch and malt endosperm being coated with protein
  - Less oxidation, because of less formation of hydrogen peroxide (H_2O_2, a potent oxidizer)
  - Improved proteolysis and amylolysis (breakdown of proteins and conversion of starch into sugar, respectively)
- Less polyphenol oxidation, so a paler wort/beer (oxidized polyphenols are colourants) and a higher carry-over of hop's and malt's inherent antioxidative power to the final beer
- Less unsaturated fatty acid oxidation—so less aldehydes, like E-2-nonenal (cardboard flavour)—both enzymatically (through lipoxygenase) and non-enzymatically (through radical-induced autoxidation)
- Less astringency (coarse bitterness) in the final beer—because of less proanthocyanidin oxidation—and a more refined beer flavour in general
- Better beer colloidal stability
- Less stale/oxidized wort and improved flavour stability overall (a fresher/crispier tasting wort)

Unfortunately, when it comes to hot side aeration, home brewers are at a disadvantage compared to (bigger) commercial breweries, because home brewing elicits a much higher oxygen ingress due to a larger surface-area-to-volume ratio. The good news is that home brew setups are extremely flexible and certain oxygen-introducing production steps, that a large brewery will have to deal with, can therefore be avoided more easily (e.g. big tank transfers, force carbonation, addition of residual beer).

Apart from not splashing around hot liquids, other examples of limiting upstream oxygen are 'wet milling' and/or blanketing the malt mill with inert gas (nitrogen or carbon dioxide), deaerating the brewing water (e.g. by boiling it, which will also help remove the chlorine), bottom filling of the mash tun and boiling kettle, usage of a 'mash cap' during mashing, avoiding turbulence during transfer or stirring, etc. While these actions may not make a huge impact by themselves, many (renowned) brewers feel that these precautions do make a difference in flavour and shelf-life when combined.

Adding antioxidants

'Antioxidant' is a term widely used, but surprisingly difficult to clearly define. A basic description would be that it is any substance that delays, prevents or removes oxidative damage. Antioxidants can do this in a number of ways, e.g. by quenching free radicals or other reactive species, chelating transition metals, becoming oxidized themselves in place of other biomolecules, etc.

Beer is naturally rich in **antioxidants**, which help **block oxidation**:

- Polyphenols: scavenge free radicals & reactive oxygen species, inhibit lipoxygenase, and chelate transition metals
- Melanoidins: scavenge reactive oxygen species
- Sulphur dioxide and other sulphites: scavenge free radicals and bind carbonyl compounds
- Chelators (phytic acid, amino acids, melanoidins, …): chelate transition metals

If it only were this simple… Unfortunately, it is not. Oxidative mechanisms are **immensely complex**, which is the reason why 'adding antioxidants' is listed under 'controversial'. Whether a chemical entity behaves anti- or pro-oxidant depends highly on the type and the concentration of the compound, their oxidation state, the pH, the type and concentration of transition metals present, the matrix, etc. It can be very difficult to make clear-cut predictions and what works in one medium might not work in another.

Here are some brewing examples to illustrate the intricacy: Melanoidins have also been known to exert pro-oxidant activity and catalyse oxidation of higher alcohols into their equivalent aldehydes. Polyphenols can reduce transition metals back to their pro-oxidative form and small/simple polyphenols (such as gallic acid) may exhibit pro-oxidant activity once oxidized. There is also the matter of adding vitamin C (ascorbic acid)—a well-known antioxidant found in foods—to the mash or beer, which some home brewing books will even recommend doing. However, ascorbic acid's beneficial effects on beer flavour stability are dubious at best, as it tends to behave pro-oxidatively at the (low) concentrations you would employ in beer.

This being said, adding **sulphite** (e.g. potassium metabisulfite)—another well-known antioxidant—to beer will bind carbonyl compounds, eliminating many of the "stale" notes. That their use is restricted or prohibited in some countries is nothing to worry about as a home brewer, but be aware that too much sulphite is toxic to yeast, causes beer to taste "sulphury" (like rotten eggs or burned matches) and can invoke allergic reactions in some people.

Bottle conditioning

Although the general consensus is that **bottle refermentation aids flavour stability**, there is still some room for debate, as it does **not** come **without its risks**.

Bottle conditioning benefits shelf-life because active yeast will absorb small amounts of dissolved oxygen remaining in the beer. Contrary to popular belief, it will only marginally remove any headspace and/or ingressing oxygen. Yeast will, however, reduce several aldehydes to alcohols, making them less flavour-active (which is a good thing); and it will assimilate residual free amino acids (another good thing, as these can be converted into off-flavour aldehydes with time). Flavour-wise, bottle conditioning can also add an extra layer of "complexity" and uniqueness to the beer. To that extent that certain styles, of which many are Belgian strong ales, cannot be accurately reproduced without bottle conditioning.

The downside of bottle conditioning is that, after this active refermentation phase, the beer will remain in contact with the yeast during the whole storage period. This sometimes results in the yeast dying, especially if stored inappropriately, resulting in the cell contents spilling out into the beer—also known as ‘yeast autolysis’. This causes an immediate flavour change: a sharp, bitter taste, often called “yeast bite”, accompanied with a meaty, sulphury edge, caused by the re-release of amino acids and yeast nucleotides. Indirect flavour changes also occur, because of altered acidity, lipid release (rancidity) and enzymatic digestion—mainly by yeast proteases—of beer proteins (resulting in haze and reduced head retention). All the yeast-accumulated metal ions will also be released back into the beer, where it shall wreak oxidative havoc.

Using the same yeast from primary fermentation, as done by most amateur home brewers, will increase the chance of complications; as this yeast is in a depleted and stressed state by then, because of being in a low pH and high ethanol environment. Even when using fresh, healthy yeast, bottle refermentation can get tricky at times: Miscalculations can result in under-carbonation (flat beer) or over-carbonation (gushing, or worse, exploding bottles). Floating/suspended yeast will cause haze. And there is a risk of introducing unwanted spoilage organisms (such as lactic acid bacteria or wild yeast).

Innovation in home brewing (experimental)

As a finishing note, here are a few concepts that home brewers can experiment with that might benefit flavour stability:

- Brewing without boiling

A brewing process that completely skips the wort boiling step is nothing ground-breakingly new. Quite the contrary; it is likely that a lot of prehistoric beers were “no-boil” or “raw” ales. While making beer this way will definitely cut down on the heat load and hot side oxidation (depending on the mash length), it comes with its own set of technical challenges (such as more remaining protein). Nevertheless, some very interesting and successful beers have already been made this way.

- Brewing with green malt

Traditionally, brewing is done with kilned or roasted malt. However, it is not impossible to brew a good beer even with 100 % green/unkilned malt (it has been done). Since this is going against the grain, the brewer will have to deal with a fair share of technical challenges; but green malt brewing comes with the advantage of introducing significantly less heat load to the wort, less reactive compounds (like free radicals, formed in the husk during kilning/roasting), likely less transition metals (roasting facilitates their release), more intact polyphenols and substantially more diastase enzymes (which could mean faster and more efficient mashing).

- Brewing with unmalted grain

Unmalted/raw grain is grain that, not only did not undergo kilning (like with green malt), but also skipped the whole process of malting altogether (steeping and germination). This causes the grain to not have its enzymes readily available for converting starch into sugar during mashing. So, when brewing with e.g. 100 % unmalted barley, addition of technical enzymes is a must. While this is not a new concept—the first commercial all-barley beer being brewed and sold in 1963—it is not a very common practice among home brewers. Nonetheless, like with the green malt, brewing with raw grain results in a paler, less heat-stressed beer with enhanced flavour stability. Since green malt has way more diastatic power than kilned malt, it might be interesting to experiment with combining green malt and unmalted barley to omit the need of having to add technical enzymes.

- Brewing without malt and without hops

This last suggestion is just to have a bit of a laugh, although there is a point to be made: While this method would definitely make for an extremely flavour stable "beer", no one would drink it. We should never lose our aim in trying to achieve perfection. At the end of the day, beer is there to be drunk, enjoyed and to have fun with. Cheers to that!

Summary

Stage	**Raw materials, equipment & additives**	**Milling**	**Mashing & lautering**	**Boiling & clarification**	**Fermentation & conditioning**	**Bottling, canning, kegging**	**Storage**
High relevance and easy to do	Add sulphite Add effective chelators (tannic acid, ellagic acid)				Use healthy yeast Ensure vigorous fermentation	Minimize in-pack oxygen: oxygen scavenging caps Avoid pick-up of iron, copper and manganese	Keep it dark Keep it cold Limit storage time
Low(er) relevance or controversial but easy to do	Use low-LOX barley		Inhibit LOX (mash-in ≥ 62°C)			Bottle-conditioning (residual yeast)	Store it upright Keep it still

High relevance but more challenging	Avoid pick-up of iron, copper and manganese		Limit heat load			Minimize in-pack oxygen: cap on foam, purge containers, limit transfers, …	
Low(er) relevance or controversial and more challenging	Add antioxidants	Flush grist with CO_2 Mill anaerobically	Limit hot side aeration		Clear wort		
			Adjust pH (if necessary)	Remove trub			
Experimental	Usage of green malt Usage of unmalted grain			No boiling, "raw ale"			

Further reading

I am part of the European Joint Doctorate Food Science (EJD) project, funded by the European Union's Horizon 2020 research and innovation programme. For those who wish to know more about this project, about us (seven international early stage researchers) or about the work we do, please check out the official website: https://ejdfoodsci.eu/

In a nutshell, my research focusses mainly on the removal of transition metals during brewing in order to improve flavour stability. My EJD colleagues are working on topics such as: brewing with innovative raw materials, the effect of malt bill on metal composition in wort, the influence of malt quality and malting process on beer staling compounds, brewing with green malt, the evolution of aldehydes during brewing, fermentation and storage, and the monitoring of yeast performance and fermentation through proteomics.

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