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Provocation: prolonged maturation of beer is of unproven benefit

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Abstract

Approaches to brewing are suffused with dogmatic insistence that certain techniques are unequivocally linked to the delivery of quality products. Amongst these belief sets is the perseverance with prolonged maturation (or 'conditioning') times post-fermentation. Historically the justification for these lagering techniques was to allow settling of solids, carbonation, flavour maturation and removal of chill haze entities. As science and technology have advanced it is unequivocally the case that solids and chill haze precursors can be dealt with in short order and without the need for lengthy treatments.

Equally it is perfectly possible to deliver specified levels of carbonation without the need for all the carbon dioxide to be introduced via yeast action. However, there remain many who feel that the nature of carbonation differs depending on which approach is taken. Herein lies one of the research areas that the author proposes. The perception of carbonation is not primarily due to bubble release on the palate, but rather is through the detection of carbonic acid. Is there a difference in the availability of this form of the gas depending on the mode of carbonation and to what extent does the adsorption of the carbonic acid on polypeptides in the beer have a role to play?

In terms of flavour, the advocates for lagering insist that there needs to be a handling of vicinal diketones, acetaldehyde, and hydrogen sulphide. However, all of these can be controlled through attention to primary fermentation. Then, the proponents for maturation insist that there is a desirable release of non-volatile materials into beer, which substances supposedly benefit the balance and mouthfeel of the lager. These include amino acids and nucleotides. It seems to this author however that the likeliest explanation for the greatly increased levels of these materials and of pH is autolysis of yeast. This, together with the disadvantageous impact of increased free amino nitrogen and higher pH on aspects such as biological stability, flavour stability and foam, should convince any brewer that there is a sound argument for avoiding the prolonged contact of beer with yeast. Indeed, a metabolomic approach to studying changes in non-volatile substances under conditions where there is little or no autolysis, revealed no detectable changes in any entity.

The author is open to being convinced that there are yet unidentified materials that are developed (whether through the action of viable yeast or by yeast autolysis) as beer is stored, substances which can be proven through sound organoleptic investigation to benefit the flavour of beer. Perhaps the Japanese term, kokumi, is what we are looking for here: 'rich taste'. This is believed to be afforded by γ-glutamyl peptides and, inter alia, these are to be found in yeast extracts. Herein lies the second experimental approach that the author recommends for pursuit.

Keywords:
Lager; maturation; conditioning; carbonation; stabilisation; flavour; accelerated processing

Introduction

'In traditional lager brewing, modifications of taste and aroma are implicitly associated with long cold and active secondary fermentation.' Thus wrote Charles Masschelein in his Centenary Review in the *Journal of the Institute of Brewing* (Masschelein, 1986).

Ferkl and Curin (1979) in the *Technical Quarterly of the Master Brewers Association of the Americas* were equally adamant:

'We assume that the higher beer consumption in Czech countries is, besides other factors, due to the specific organoleptic properties of the beer which have developed during a centuries-long tradition of beer production. By this is meant a production of a classical type of beer, characterised by all-malt brews, decoction brewing procedure, high hopping rate (using exclusively Saaz hops), cold primary (bottom) fermentation, cold and long maturation time.'

The merits of 100% malt grists and decoction are topics for other papers. Here I will focus solely on the issue of prolonged cold conditioning and maturation in relation to the production of bottom fermented beers. I will conclude that the evidence suggesting that it is an absolute requirement is tentative and subjective.

The claimed purposes of lagering

In his classic textbook, De Clerck (1957) summarises the 'objects of conditioning beer':

1. To allow yeast and 'amorphous, turbid matter' to settle out.
2. To carbonate the beer 'by secondary fermentation, or by artificial carbonation'.
3. To improve flavour.
4. To precipitate chill haze and prevent it recurring in filtered beer.
5. To keep beer in a reduced state and avoid the access of oxygen.

De Clerck (1957) suggests that the 'normal' lagering time for a 12° Plato beer is 2.5-3 months, claiming that this is optimum regarding 'mellowness and flavour'. Longer periods lead to a diminution in quality due to the sedimentation of 'colloids' and a loss of body resulting in a thin taste. He suggests that the lower the gravity, the shorter the lagering period. In referring to the 'stench' (*goût de jeune* or *Jungbukett)* associated with green beer he mentions the potential for cutting down on maturation time by purging with carbon dioxide.

Masschelein (1986) adds to the list of functions of lagering by suggesting that there is the 'adsorption on the surface of the yeast of various non-volatile materials' and adds that 'progressive changes in flavour and aroma are dependent upon the whole of transformations associated with beer clarification and slow stripping of unwanted volatiles by the generation and release of excess carbon dioxide'.

Let us consider these various requirements one by one, leaving the most contentious matter of flavour to last.

To allow yeast and other solids to settle out

In an era with widespread employment of Nathan's cylindroconical fermenters, of centrifuges and filters there are surely few who would argue that the matter of solid-liquid separation as being a major driving force for the retention of prolonged maturation.

To achieve the required carbonation of the beer

Noting that De Clerck does seem to allow for either natural or forced carbonation, the question needs to be asked: is there any difference in the nature and quality of the carbonation between the two approaches, as some claim?

This author has been unable to locate any serious scientific publication that addresses this issue, i.e., whether the perceived carbonation afforded by carbon dioxide produced by yeast via fermentation and in maturation differs in any way from that delivered by physical dosing of the pre-formed gas. This is not to say that differences do not occur, but there appears to be no definitive study in this area, whether in beer or other types of carbonated alcoholic beverage, notably champagne (Liger-Belair and Cilindre, 2021).

Carbon dioxide in solution is in an equilibrium between CO_2 and carbonic acid:

$$CO_2 + H_2O \leftrightarrows H_2CO_3 \quad \text{(Eqn.1)}$$

The equilibrium constant for this reaction is 1.7 x 10^{-3} at 25°C, so most of the carbon dioxide does not take the form of carbonic acid. That which is in the form of carbonic acid will dissociate into bicarbonate:

$$H_2CO_3 \leftrightarrows HCO_3^- + H^+ \quad \text{(Eqn.2)}$$

The relative balance of carbonic acid and bicarbonate is dependent on pH. The pKa for this equilibrium is 3.6 at 25°C. Accordingly, at the pH range of most beers, the preponderance of the carbonic acid is in the form of bicarbonate.

There may be mileage in pursuing this area. For example, to ascertain whether small variations in pH and perhaps other materials in solution that correlate with the mode of carbonation, have a role to play in significantly impacting the impact of CO_2 on the palate.

Perhaps there is something to be gained by delving further into the matter of the impact of carbon dioxide on mouthfeel, as eloquently reviewed by Carstens and colleagues (Simons et al, 2017). As described, the tingle associated with CO_2 is not (as is assumed to be the case by many) on account of the bursting of bubbles on oral tissues. Rather it is the chemesthetic detection of carbonic acid by nociceptive (pain-detection) fibres in the lingual nerve (that which serves the tongue) and neurons in the trigeminal complex.

Thus, any factor that increases the concentration of carbonic acid as opposed to carbon dioxide will increase the prickle factor.

The first suggestion that the prickly sensation from carbonated drinks was not due to the bubbles of CO_2 per se came from Hansson (1961) who showed that the perception was nullified by inhibitors of the enzyme carbonic anhydrase. This enzyme catalyses the reaction:

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad \text{(Eqn.3)}$$

The carbonic acid will dissociate into bicarbonate and a proton (equation 2). However, the key point may be this: as noted earlier, most of the CO_2 in beer remains in the form of CO_2 rather than carbonic acid and its dissociation product. However, if carbonic anhydrase is present, then this will increase the conversion of CO_2 into carbonic acid and thence its dissociation products and increase the perception of carbonation on the palate. Yeast does produce a carbonic anhydrase (Lehneck and Pöggeler, 2014). Could it be that the continuing presence of yeast in beer permits these interactions to occur and thus increase the extent to which a given degree of carbonation is detectable? If this is the case, then it is entirely possible that the sensation obtained from 'natural' carbonation would be greater than that imparted by CO_2 dosed into beer that no longer contains yeast. However, it may remain that the carbonic anhydrase in the human system is much more relevant in this regard.

An alternative explanation for differences in the quality of carbonation may lie in other differences introduced into the beer that impact the extent of release of CO_2 on dispense and the form which the bubbles take. This focuses our thinking on the nucleation phenomena, with smaller sites affording finer bubbles (Prins and van Marle, 1999) and an attendant possible impact on both mouthfeel (Langstaff et al, 1991) and the extent of release of aroma molecules (Ono et al 1983). Liger-Belair and Cilindre (2021) draw attention to the role of bubble bursting in champagne in releasing aroma molecules. Even if this is the explanation for beer, it would presumably remain possible to match the beers produced in both ways via the mode of dispense.

Alternatively, the claimed difference in perceived quality between naturally and force carbonated beers may be on account of something entirely different. Basarova et al (2017) discuss the 'physical fixation' of CO_2. They claim that carbonic acid molecules - as opposed to CO_2 - are adsorbed onto protein complexes through ionic interactions and this is increased as the pH is lowered. They claim that this is disrupted by metal ions such as iron. Could we consider this in relation to the above discussion of carbonic anhydrase from yeast, which would be important in generating the molecular form in which the carbon dioxide binds to proteins? This entire topic of the nature of carbon dioxide and the related carbonic acid and bicarbonate in beer is worthy of more extensive consideration.

To precipitate chill haze and prevent it recurring in filtered beer

Even if we allow for the essentialness of a post-fermentation conditioning stage for this purpose, it has been demonstrated that the precipitation of chill haze material is primarily dependent on the extent to which the temperature is decreased and not the residence time in storage (Miedl and Bamforth, 2004). In other words, it is preferable to employ a short time at a lower temperature, such that 1 day at -2°C is more effective than many days at +2°C.

Indeed, it might be argued that in view of the availability of treatments such as polyvinylpolypyrrolidone (PVPP) to remove polyphenols (O'Reilly, 1994), silica gels to adsorb polypeptides (McKeown and Nock, 1996), tannic acid to precipitate polypeptides (Mussche, 1994) and enzymes such as prolyl endopeptidase (Lopez and Edens, 2005) to hydrolyse the proteins that cause chill haze (Siebert et al, 1996), there no longer remains a priori need for conditioning to introduce colloidal stability into beer.

To keep beer in a reduced state and avoid the access of oxygen

This warrants little further discussion. This is an imperative rather than a justification for prolonged lagering. Today, Brewers have a far better understanding of the impact that oxygen and oxidising reactions have on product stability, including flavour stability (Baert et al, 2012). The minimisation of oxidation at all stages of the process is emphasised and there is nothing unique about this in the maturation phase. Indeed, it would be an argument for minimal conditioning time unless the removal of oxygen or oxidising power was inherently required at this stage.

To improve flavour

Which leads us to the matter of flavour. Turning again to Masschelein (1986): 'It is generally recognised that beer flavour improves during storage. Many studies have shown that the adjustment of the concentration of undesirable compounds such as acetaldehyde, vicinal diketones and sulphur compounds, play an important part from the point of view of the time required to produce fully matured beer. If this concept of the effect of maturation is true, it should, however, be recognised that many other changes in the composition of the non-volatile fraction occur during that period and that these modifications are also known to have significant effect on the quality of the final product. The observed modifications are generally expressed as better flavour association with concomitant increase in palate fullness and mouthfeel. The fact, that such modifications only occur in the presence of yeast, suggests that some correlation must exist between taste improvements and changes in yeast metabolism during lagering. However, release of amino-acids, peptides, nucleotides and organic and inorganic phosphates are not only dependent on the yeast itself, but also on its physiological state and its physical behaviour and on many other variables such as temperature, time, turbulence created by the secondary fermentation, and the shape, geometry and capacity of the storage vessels.'

Volatile substances

Historically, the volatile substances of primary concern in demanding the prolonged storage of beer were the vicinal diketones, acetaldehyde and hydrogen sulphide. Now, with the comprehensive understanding of the factors that impact the metabolism of these molecules, it is entirely clear that all of them can be dealt with in short order and without the need for prolonged contact with yeast.

Regarding diacetyl and pentanedione, the vicinal diketones of concern, they can be dealt with in primary fermentation inter alia through the use of a temperature rise during fermentation (Inoue, 2008), the use of kräusening (Macdonald et al, 1984), the employment of acetolactate decarboxylase (Hannemann, 2002) and by more rapid post-fermentation processes involving thermal breakdown of the two VDK precursors followed by the use of immobilised yeast to remove the diacetyl and pentanedione (Pajunen et al, 1989).

Acetaldehyde should be dealt with by ensuring a healthy and vigorous fermentation (Geiger and Piendl, 1976), as indeed is hydrogen sulphide (Nagami et al, 1980.). Further, it has long been recognised that traces of copper, either added or leached from brewing vessels or piping, are sufficient to remove hydrogen sulphide (Pfisterer et al, 2004).

Masschelein (1986) details the production of short and medium chain length fatty acids if the removal of sedimented yeast in maturation is incomplete or delayed. He refers to the caprylic character as being 'yeasty'. It is not entirely clear whether he is cautioning against this occurrence or simply observing that this is one of the ongoing implications for flavour of prolonged contact of green beer with yeast during conditioning. It serves to remind us, though, that the continued presence of viable yeast in beer will enable ongoing changes to take place in the level of flavoursome volatile substances in beer.

Prolonged contact of beer with yeast leads to an increase in the levels of methanethiol, ethanethiol and dimethyl sulphide (DMS) in beer (Stewart and Ryder, 2019). The presence of DMS can be readily explained by the reduction of dimethyl sulfoxide (DMSO) by the methionine reductase of yeast (Anness and Bamforth, 1982). It has been demonstrated how this conversion occurs to a far greater extent under low levels of free amino nitrogen (FAN) (Gibson et al, 1985) and at lower temperatures (Anness, 1980). Indeed, there is evidence for non-enzyme catalysed reduction of DMSO, by reducing agents in beer (Bamforth, 1985). Considering that DMS is widely (though not universally) considered to be a flavour defect (Lustig et al, 1998), this can hardly be an occurrence in lagering that is desirable by most!

Cooper et al (2013), as well as highlighting the importance of removing any remaining undesirable volatiles not dealt with in fermentation, suggest a significant role for the adsorption of unwanted materials by adsorption to yeast and other settleable solids in conditioning.

Non-volatile substances

Masschelein (1986) says 'In contrast to the vast amounts of studies undertaken to elucidate the importance of volatile flavour-active compounds in determining the characteristic aroma of young beer and aroma changes over the lagering period, the role of non-volatile materials released by yeast has only received little attention.'

His claim is 'The observed modifications are generally expressed as a better flavour association and, particularly, by gradual increase in palate fullness and mouthfeel. The fact that these flavour characteristics are lacking in beers from which yeast has been removed immediately after primary fermentation supports evidence that some correlation must exist between taste improvements and changes in yeast behaviour during lagering'

Masschelein and van der Meersche (1976) detail the changes occurring in beer stored for 40 days in a horizontal tank, taking measurements from the middle and bottom of the tank. It is striking that the changes were vastly greater in the bottom of the tank and thus linked to the settled yeast. These changes included (a) an increased pH (to 5.9 from 4.1 at the end of fermentation); (b) a greater than 10-fold increase in the level of FAN and (c) a similar

increase in the level of invertase. It was also shown that there was an increase in the level of inorganic and organic phosphates together with a massive release of nucleotides. Unsurprisingly there was a major decrease in the viability of the yeast cells.

Masschelein (1986) was quite clear: 'The extent to which excretion and autolysis are important in flavour maturation and its dependency on yeast strain, fermentation conditions and environmental factors are currently ill defined.'

He did claim that yeast viability and fermentation capability were retained for several weeks. He relates the increase in release of invertase and α-glucosidase alongside the decrease in viability to changes in cell permeability and attendant release of autolysis products. He is at pains to point out though:

'It should be emphasised, however, (that) two distinct phenomena are involved. Excretion only modifies selective permeability of the (yeast) plasma membrane, whereas autolysis entails rupture of the latter with non-selective release of protoplasmic material. Such distinction is important because one could easily conceive that it is exclusively the evolution of the physiological state of the yeast during storage which will determine the profile of the released compounds.'

It is not clear from this work (Masschelein 1986; Masschelein and Van de Meerssche, 1976) to what extent the authors are differentiating between the action of metabolism of viable yeast as opposed to autolysing yeast in delivering the supposed benefits of prolonged conditioning. Indeed, we should also compare these observations with those of others who applied metabolomics in finding no major difference in the level of a wide range of non-volatile substances between beer aged in the presence or absence of yeast, nor indeed any substantial changes in levels as compared to beer at the end of fermentation (Metrulas et al, 2019). This author suggests that the difference reflects the extent to which autolysis of yeast was occurring in the respective experiments in the two laboratories. Taking the findings from the Masschelein laboratory at face value and without attempting to differentiate between viable yeast activity and autolysis, let us consider the implications of the changes occurring in the beer. An increase in the level of amino acids would be to the detriment of microbiological stability (Bokulich and Bamforth, 2013) and flavour stability (Baert et al, 2012). Further, an increase in pH would also be to the detriment of foam stability (Melm et al, 1995). With regard to head retention, it is also now recognised that the release of proteinase A in prolonged contact of beer with yeast is greatly disadvantageous (Brey et al, 2003).

And what is the evidence for a link between the changes reported by Masschelein and the improvement in mouthfeel of beer? In their review of beer mouthfeel, Langstaff and Lewis (1993) make no mention of either amino acids or nucleotides amongst the many substances that have been put forward as materials that impact the mouthfeel of beer.

Clues from other alcoholic beverages?

Maturation stages are firmly established in the production protocols for other types of alcoholic beverage. Might these offer some guidance for further study of maturation in beer?

Distilled beverages

Discussions of ageing in the production of whisky for the most part centre around changes taking place during storage in wooden containers (Conner et al, 2003). Whilst this is relevant to the discussion of changes in beer during barrel ageing, this is outside the scope of the present article. (The reader is referred to Sterckx et al (2012a, b), Wyler et al (2015) and Bossaert et al (2022) regarding the ageing of beer in wood.)

The changes taking place in whisky during storage are split into so-called 'additive activity' (reactions that introduce or form new flavour-active substances) and 'subtractive activity' (reactions in which such substances are either removed or transformed) (Conner et al, 2003).. The former type of change is particularly associated with extraction of materials

from wood. In terms of subtractive activity, changes may arise through evaporation, adsorption, or chemical reactions (Conner et al, 2003). It will be realised that the former two processes are heavily dependent on the surface to volume ratios of the container. Accordingly, one would anticipate much more change in a vessel such as a wooden cask than in a multi-hectolitre stainless steel lagering tank.

Amongst the chemical changes that have been reported are the oxidation of ethanol into acetaldehyde and acetic acid (Reazin, 1981) and (ironically) the oxidation of DMS to DMSO (Fujii et al 1992). There are also esterification and transesterification reactions (Reazin 1981). Acetals are produced from aldehydes, changes in which sour and pungent aromas are transformed into fruitier characters (Perry, 1986). It will be realised, of course, that there are very few beers that have alcohol contents as high as whisky. The extent to which changes occur in most beers which contain less than 10% ABV is going to be far less. Moreover, aging periods involved in whisky production are generally far longer than would be involved in even the lengthiest maturation protocol in a brewery. Thus changes to sulphur compounds in whisky such as 3-(methythio) propanal, dihydro-2-methyl-3(2H) thiophenone, ethyl 3-(methylthio)propanoate, 3-(methylthio) propyl acetate, 3-(methylthio) propanol, DMS, dimethyl disulfide (DMDS), DMTS, 2-thiophenecarboxaldehyde, 5-methyl-2-thiophenecarboxaldehyde, benezothiophene, and benzothiazole occur over a timescale of years (usually at least three) rather than weeks or a few months (Masuda and Nishimura, 1982, Wanikawa and Sugimoto, 2022).

Wang et al (2023) have recently published a review of the changes occurring during the ageing of several distilled beverages. Amongst the chemical species reported to change during maturation (without directly invoking materials derived from or lost to wood) are (a) increased levels of organic acids; (b) an increase followed by a decrease in alcohols; (c) an increase in the levels of aldehydes; (d) an increase in the level of esters, followed by a decrease; (e) an increase in the level of furans, such as furfural; (f) an increase in the level of ketones; (g) an increase in pyrazines; (h) a decrease in sulphur-containing substances and (i) an increase in terpenes and norisoprenoids. Transformations involve oxidation (impacted by metal ions such as iron and copper), hydrolysis, esterification and the Maillard reaction. Perusal of this detailed summary are pertinent when one considers the complex chemistry involved in flavour instability in beer, well reviewed by Vanderhaegen et al (2006).

In other words, the very changes that occur over prolonged periods in deliberate and desired spirit maturation overlap closely with those that brewers are worried about in the context of flavour deterioration in packaged product!

Wine

Jones-Moore et al (2021) draw attention to the potential importance of polysaccharides, including those derived from yeast, in wine quality. Here is an area perhaps worthy of further investigation in beer: is there an impact on mouthfeel, for example?

Of all the wines, perhaps it is champagne, with its high carbonation, that may offer more clues if we consider the impact of prolonged maturation periods. Liger-Belair and Cilindre (2021) recently reviewed the role of carbonation and flavour in this type of product. Reading this article does not reveal any obvious clue as to why the mode of carbonation employed has any direct impact on the nature of the bubbles produced or their impact on the flavour of the product.

Alexandre and Guilloux-Benatier (2006) discussed the importance of yeast autolysis occurring in the production of sparkling wines. They refer to the released amino acids as being precursors (via deamination and decarboxylation reactions) of flavour active materials such as lactones, for example 3-hydroxy-4,5-dimethyl-2(5H)-furanone (sotolon) which has a green nut or curry aroma. Reference is made to some peptides having either sweet or bitter tastes, and the authors do suggest that the peptides may contribute to the foaming properties of champagne. Alexandre and Guilloux-Benatier (2006) mention the role of released mannoproteins in protecting against haze development and their importance in preventing precipitation of tartaric acid, though this is hardly relevant for beer.

Nucleotides such as 5'-adenosine monophosphate and 5'-guanosine monophosphate that are produced from the hydrolysis of nucleic acids in autolysis may have flavour impacts, perhaps more though influencing the flavour delivery from other components rather than of themselves (Pozo-Bayon, 2009).

Styger et al (2011) review the flavour of all types of wine, including changes that occur in maturation. Again, leaving aside the role of wood, they write about ageing of wine on the lees (residual yeast cells), leading to a decrease in the concentrations of the compounds that impart a fruity aroma together with an increase in long-chain alcohols and volatile fatty acids. Specifically, they invoke the importance of autolysis and the release of amino acids, peptides, and proteins including mannoproteins, with the fatty acids giving rise to volatile esters, aldehydes, and ketones.

I am particularly struck by the concluding paragraph of Styger et al (2011):

'Lastly, it is also important to keep in mind that the appreciation of wine is entirely subjective. People will and should differ on the relative merits or attributes of a specific wine. After all, much enjoyment can be derived from discussing these differences in perception, and wine is certainly unique as a food product in creating passion and interest for detecting and debating the merits and demerits of individual products. There are certainly enough styles, cultivars, and wines on the market to satisfy all tastes.'

The chemical changes described in the maturation of spirits and wine are surely (and unsurprisingly) like those that occur in beer during ageing in package. It is customary to consider such changes in a negative way, striving as most brewers do to seek prolonged shelf life in their beers. Is it nothing more than a case of those insisting on prolonged maturation times for beer in the brewery feeling that it is desirable to have some of this chemistry occurring prior to packaging?

Concluding remarks

The clearest interpretation of the state of affairs in prolonged maturation is that yeast has a decided role to play. It is obvious that it is entirely possible to produce successful lager beers by attending to unwanted volatiles (notably VDKs, acetaldehyde and hydrogen sulphide) in primary fermentation. Any requirement for retaining beer storage as a stage in the process is at best an issue of beer stabilisation and clarification, either of which can be attended to by alternative processing techniques. Carbonation can be readily adjusted by pin-point carbonation or the use of membrane technology (Freeman, 2006). Shorter or longer time periods contacting green beer with yeast will of course present the opportunity for volatile substances to change in quantity, whether by scavenging by yeast (and this will include undesirable carbonyl substances; Debourg et al, 1994) or by further production by yeast. This latter activity will include the production of short chain fatty acids and various organic sulphur compounds, including DMS. Most brewers would not be seeking this in their beer.

Although some of the other changes linked to yeast may reflect active metabolism, it seems altogether more likely that the dramatic changes reported by the Masschelein laboratory (enormous increase in pH, extensive release of amino acids, nucleotides, inorganic and organic phosphates) reflects autolysis. Is this the basis of the 'marrying' to produce a good mouthfeel as described by Delvaux (1996)?

To this author it all seems unsatisfactory and imprecise as a justification for continuing with prolonged lagering periods, totally accepting that those beers that have long been produced with lengthy storage will have characters (whether desirable or not) that are on account of the approaches and not despite them. One is repeatedly told that folks have evidence for the superiority of these techniques for lager production and yet there is no attempt to scientifically link the claims to hard analytical date. And thus, we have descriptions such as those of Ferkl (1979) in which they rate 'flavour quality' on a scale of 1 (the best) to 9, claiming that the score rises from just above 6 to between 2 and 3 in 14 weeks of maturation, but then there is a

decline linked to autolysis. There is no indication that this is any other than a subjective rating and the authors give no indication of the robustness of their organoleptic approach in the ways expected by Meilgaard (2001). How many tasters? How representative are they? Trained or not? Etc.

In the absence of strong evidence to the contrary, my opinion would coincide with those of Hashimoto et al (1960) that 'no single flavour component affects flavour change during lagering and no benefit in taste was derived from prolonged lagering'.

However, lest I be accused of closed mindedness, I do feel that there is every justification for definitive and fact-based pursuit of substances that may be released during maturation, whether by active yeast metabolism or autolysis, and which genuinely can be shown to impact quality attributes of beer, such as mouthfeel. Mannoproteins surely deserve more attention in a brewing context. I am also curious about γ-glutamyl peptides of the type described in yeast extracts by Liu et al (2015). These compounds have been linked to the sensation of kokumi ('rich taste') which refers to the mouthfulness, thickness or complexity of foods (Yang et al, 2019). Does addition of this type of material benefit the quality of beer? If so, how might the levels be optimised in beer without jeopardising other aspects of beer quality?

There may still be some variables worthy of further research in the context of the impact of maturation. One example would be the contribution that ageing has on the quality delivery from different lager strains of the Frohberg and Saaz types (Gibson, 2013). It is also possible that there are molecular events occurring in programmed cell death (Carmona-Gutierrez, 2010) that are different to those arising from cell autolysis and that this will impact beer quality and vary depending on the conditions (e.g., temperature) to which the beer and yeast are exposed to.

Until such time as there is a scientifically proven relationship between prolonged maturation and beer flavour, this author will retain his scepticism and advocate for a more accelerated approach to lager production, one that is already practiced successfully in the production of highly prized brands (Bamforth, 2022).

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