UC Davis

UC Davis Previously Published Works

Title

Enzymes, egg white, and eccentrics: Memories from 37 years of research in the brewing industry

Permalink

<https://escholarship.org/uc/item/5914q1dw>

Journal

Journal of the American Society of Brewing Chemists, 74(1)

ISSN

0361-0470

Author

Bamforth, CW

Publication Date

2016

DOI

10.1094/ASBCJ-2016-1122-01

Peer reviewed

1BIOGRAPHICAL REVIEW

2

3Enzymes, Egg White and Eccentrics

4Memories from 37 years of research in the brewing industry

5

6Charles W. Bamforth,¹ *Department of Food Science and Technology, University of California, Davis, CA*
795616

8¹ Corresponding author. E-mail: cwbamforth@ucdavis.edu; phone: +1-530-752-9476; fax: +1-530-752-
94759

10

11

12

13

14

15

16

17

18

1

2

19I was 10 years old and already I had a rather respectable chemistry lab in our home near Wigan, in
20Lancashire, England. It was shared with elder brother John who taught me the essentials of valence,
21balancing equations and much more at least two years before my first ever chemistry class at Up Holland
22Grammar School. From the age of 13 to 18, however, I was hardly a dedicated student of terribly much at
23school, being rather more focused on sport, especially playing rugby for the various school teams, and
24(in the latter part of the age span but still at a premature age in legal terms) the pub. However the very
25limited biochemistry that we studied in A Level Biology captured my imagination and accordingly I felt
26fortunate to be accepted by the University of Hull to study for my B.Sc in that subject.

27

28Immediately after my arrival in Hull in 1970 I realized straightaway that I had chosen well. I loved the
29topic and worked exceedingly hard at it, with the theory coming to me much more comfortably than the
30more hands on aspects. The Biochemistry department at Hull was very much focused on matters
31microbial, and guided tours were offered past my bench as I did my sterile plating – to show how NOT to
32do it. I was never the most meticulous or tidy worker in the lab, no matter how much the science was
33intriguing me. I always seemed to be in a hurry – including on the day I dropped a titanium centrifuge
34rotor valued at £700 all those years ago. (They mounted a plaque on it and made it the prize for the
35dumbest act anyone did after that point.) The head of the department, Professor Eddie Dawes, was livid
36and never forgave me until I was awarded a D.Sc² at Hull 20 years later. Dawes was a celebrated magician
37in his off duty moments³ – it disappointed me that he could not wave his wand and make the rotor
38whole again.

39

40Someone who was quite the opposite of me when it came to laboratory dexterity was Chris Boulton,
41latterly of course of Bass, the University of Nottingham and even more recently SAB-Miller, who would
42become a close lab mate of mine at Hull and who has been a dear friend now for over 40 years.

43

44Upon graduation I was much undecided on what to do next – there has never been a master plan at any
45stage of my life. I came from a long line of teachers and seriously thought of heading off to a college to
46study to become an instructor in Technical Colleges. Fortunately a junior faculty member at Hull, Melvin
47Midgley, convinced me that I could do research: “If you can cook and create in the kitchen you can do
48research.”

49

50I was blessed with my choice of lab. Dr. Peter Large was exactly the right guy for me. Himself a somewhat
51chaotic presence when he ventured into the lab, he was however of a brilliant mind and by nature a
52lovable, placid Christian gentleman. The lab was tiny, in the attic of the oldest building on campus and,
53looking back, a veritable death trap. On a daily basis there were four of us in there: myself; Chris
54Boulton, who was Peter’s technical support; David Brook, a tremendously helpful post-doc whose lack of
55height caused Chris to call him “the Micro Biologist”; and an eccentric red-haired Scots lassie called Hazel
56McDougall who would drift away.

57

58**Methylo**trophs

59

60The focus of the lab was methylotrophs, bacteria that grow on single carbon compounds such as
61methanol and methylamine. At the time there was huge interest in exploiting these for their industrial
62value, in particular the production of what was then called Single Cell Protein: food as bacteria or yeasts
63grown on cheap and abundant feedstocks. It wouldn't pan out economically.

64

65My PhD project was dedicated to studying the enzyme N-methylglutamate dehydrogenase, which plays a
66role in the oxidation of methylamine by the organism then known as *Pseudomonas aminovorans* (now
67re-named *Aminobacter aminovorans*). I couldn't have started my career as an enzymologist with a
68tougher challenge. The enzyme is membrane-bound and of low specific activity. I had to work up huge
69quantities of the organism in 5 gallon jars to render enough cells to give (after purification) sufficient
70enzyme for just a handful of experiments. The learning curve, however, was exponential and I was able
71to make a pretty good fist of the kinetic analysis of the enzyme, and for that I was grateful to another
72friend and fellow student who would go on to the brewing industry, Chris Dickenson. Chris was a couple
73of years ahead of me on the PhD path.

74

75I was terribly nervous when I gave my very first presentation to a scientific meeting, to the Biochemical
76Society in Edinburgh in 1975. The audience comprised the people who had presented before me (too
77polite to leave), the people who were about to speak next (who were too busy thinking about their
78presentation to listen), Peter Large and a kindly American scientist by the name of Bill Shaw (head of the
79biochemistry department at the University of Leicester) who had once worked on a related problem.
80Nevertheless, it went well and the abstract became my first ever publication, surely the most exciting of
81one's career (58). Two peer-reviewed papers emerged from the work (59, 60) and another abstract (61),
82the latter for my second presentation to the Society, this one in St Bartholomew's Hospital in London. I

83remember to this day a member of the audience congratulating me on how I had described the
84complexities of 2-substrate kinetics. (Words of encouragement to young scientists can make a world of
85positive difference. The opposite is even truer.)

86

87The UK system is different from that in the US in that a PhD comprises research alone – no classes – and
88takes 3 years, after which you write up your thesis, on which you are interrogated by an external and an
89internal examiner. I well recall Dr. Chris Anthony from the University of Southampton turning up and
90straightway putting me at my ease by saying “relax, you have passed”, but he followed this with a
91warning that he had traveled a long way and was going to get his money’s worth. He proceeded to
92interrogate me for over 3 hours, made me carve several pages out of the thesis because I had made a
93naive assumption at the start and he also caused me to give the most garbled description of oxidative
94phosphorylation that could ever have been delivered. (Years later I actually met Peter Mitchell, the
95genius behind the chemiosmotic theory, on a train down to my wife’s folks in Cornwall. He had a lab in
96Glynn House in the beautiful valley of that name and he showed me the money that he minted himself
97in the basement. Scientists can be odd.)

98

99By now I was married (to Diane, who I have now been with for well over 40 years) and for the only time
100in my career it was she who made the running on where we would live next. I did get offered a position
101with Burroughs Wellcome in Beckenham, Kent. I also was on the radar for a teaching job at
102Charterhouse School in Godalming, Surrey but I was turned off by only being asked three questions, one
103of which was specifically about my sexual predilections. (They were different times.) However Diane was
104in the midst of getting her nursing credentials in Sheffield and our first married home was going to be
105there. Very fortunately the godfather of methylotrophy had his lab at the University of Sheffield. Rod

106Quayle was the most eminent scientist I ever worked with and the man with whom Peter Large had
107pursued his PhD at Oxford University. Again I was blessed to step into a fabulous laboratory and a
108department that included folks who had been part of Sir Hans Krebs' team when he had been in
109Sheffield. I was proud indeed to be the post-doc of such an eminence. I well recall the day that Rod
110breezed into my lab beaming, showing me the letter that advised him that he would henceforth be a
111Fellow of the Royal Society.

112

113Immediately on arriving in Sheffield I set about characterizing several enzymes. Two of them were
114alcohol dehydrogenases (ADH), however not like the ones from brewers yeast but rather those that
115utilize cytochromes to receive the electrons and which are assayed using dyes such as phenazine
116methosulfate and dichlorophenolindophenol (DCPIP, of course, has historic relevance in the brewing
117industry to assess reducing power). The first enzyme was from a phototroph called *Rhodopseudomonas*
118*acidophila* (71, 73). Alarming for me was the day I discovered a white scum growing in the vivid red
119cultures in flat sided bottles that were positioned around the light bulb providing the light energy to the
120organism. The scum represented an intruder, most likely arriving due to my shoddy technique. I was
121distraught – perhaps the enzyme I had done extensive work on was not from my chosen organism at all.
122Quayle told me to calm down, go off on vacation to my wife's family in Truro while his excellent
123technician Alan Hancock would get to the bottom of it. A couple of weeks later a letter arrived written in
124Rod's distinctive turquoise ink: "you can dispose of the red-and-white spotted handkerchief and the stack
125of warm newspapers and come back. Your enzyme is indeed from *R. acidophila*."

126

127To be fair to myself, I was usually on the ball when it came to enzyme purification and characterization
128per se. Rod used to say I had "enzymological green fingers" and would love to watch my isoelectric

129focusing columns in which I separated the very yellow ADH from the very red cytochrome c, making for a
130splendid color show. Years later I worked with another Sheffield graduate, Michael Waites, to develop a
131bioelectrochemical cell that incorporated this very enzyme, a device that we proposed for the
132measurement of alcohol in beer (165).

133

134The second ADH was from *Paracoccus denitrificans* (72), an intriguing bacterium which had been put
135forward as the likely forerunner of the mitochondrion, being engulfed by some protozoan or other to
136enter into a mutually beneficial symbiotic relationship. *P. denitrificans* was also the source of another
137enzyme I studied, hydroxypyruvate reductase (70).

138

139Finally at Sheffield I did a joint piece of work with the molecular biologist Mary O'Connor (now Mary
140Lidstrom, Vice-Provost of Research at the University of Washington in Seattle). This was a throw back to
141my interest in *P. aminovorans* and involved the isolation of mutants thereof to explore which enzymes
142have an a priori role in the utilization of methylamine in that organism (67). Like I, Mary was a post-doc
143and a third was Hans van Dijken, who nowadays is Professor Emeritus in Delft University of Technology.
144Hans was always astonished by my predilection for secrecy and reluctance to be too forthcoming about
145my research findings until they were ready for presentation to a meeting or publication. That tendency
146remains with me.

147

148**Headed South**

149

150As a post-doc you at first beaver away doing as much high quality publishable research as you can, but
151later get distracted by scrutinizing the jobs pages of *Nature*, *Science*, *New Scientist* and the like. I was in
152the running for another post-doc at Oxford University but was more intrigued by an advertisement for an
153enzymologist at the Brewing Research Foundation (BRF) in Nutfield, Surrey. I was interviewed on the
154Thursday and the job offer came to my home on the Saturday. That impressed me. (Years later coming to
155the University of California the process took well over a year and had I not very much wanted the job I
156might easily have suggested where they might insert it. Universities can be SO slow and inefficient in this
157and so many other procedures. I love the university life but despair of the archaic way in which business
158is frequently conducted.)

159

160I know that Diane was not desperately keen to move to the London area, but she supported me as she
161always has. And so I arrived in the Department of Biochemistry and Biophysics at BRF, a team headed by
162Trevor Wainwright, erstwhile of Guinness. His initial suggestion was that I should work on developing a
163high performance liquid chromatography procedure for separating dansylated amino acids. I made
164headway but the day I dissolved a sinter when trying to clean it in aqua regia was the day I told him that I
165was frustrated as heck and that I came to Lyttel Hall to do enzymology, not screw around with analytical
166methodology that held little interest for me. "So what do you want to do?" Trevor asked me and I said
167that there were two other projects in the lab that seemed to be screaming out for some enzymology and
168accordingly it was agreed that I would get involved in those. In each case we would encounter
169astonishing push back from others in the brewing industry, who simply did not believe what we were
170suggesting. Over the subsequent years we were proved to be right in both topic areas – you have to
171believe in yourself in the world of science and also must be less judgmental when others discover things
172that fall outside your belief set.

173

174β-Glucan solubilase and related stuff

175

176The first of these projects was on barley β-glucan (9, 18). Hilary Martin, a meticulous bench worker with
177copper plate writing and accomplished on the violin with the Croydon Symphony Orchestra, was
178struggling with an assay for measuring this polymer. The principle was to hydrolyze β-glucan to glucose
179using an enzyme complex from *Trichoderma reesei* and quantify the polymer on the basis of how much
180glucose was generated. Hilary had been trying unsuccessfully to remove the key contaminating enzyme
181amyloglucosidase (AMG), whose presence would cause glucose to be generated from starch and which
182accordingly would greatly over-estimate the amount of β-glucan present. I suggested we look at the heat
183tolerance of the two enzymes and duly found that the β-glucanase in the *T. reesei* preparation was much
184more resistant to heating than was the AMG, which we could remove simply by warming the sample
185(139). In due course we would find that later batches of the commercial cellulase that we were using
186presented a little more difficulty in eliminating the AMG, so I turned to *Penicillium funiculosum* as a more
187reliable option (10).

188

189Armed with this assay, I set about exploring (with Hilary's technical assistance) a dogma that had existed
190since the pioneering work of Preece (149), Meredith (86) and, later, three others at BRF: Bob Scott (152),
191Ian Forrest (104) and Denise Baxter (87). The notion was that the breakdown of the starchy endosperm
192cell walls in barley during germination and in mashing was a two stage event: an initial solubilization of
193the glucan followed by the hydrolysis of the glucan by β-glucanases. I developed a simple assay to test
194for the existence of such an activity to which I gave the name β-glucan solubilase - and I have regretted

195the name ever since. The legendary Professor Anna Macleod, an adviser to BRF, loved the work but
196hated the name I gave to it. The somewhat unapproachable Director of BRF, Charles Dalglish, who
197wasn't there terribly long in my first stint at Lyttel Hall, also was smitten with the work.

198

199Sure enough, we confirmed what others had surmised and detected this enzyme in raw barley
200(indicating that it is not a β -glucanase, since these enzymes are produced during germination). Time to
201study in detail its properties. We showed that it is heat tolerant, meaning that it survives to a significant
202extent during kilning and was able to survive mashing at 65°C (82). Clearly it most definitely was not an
203endo- β -glucanase, one of the more thermo-intolerant enzymes. From the study of its migration on (my
204favorite tool of) isoelectric focusing, its rate of thermal destruction, inhibitor specificity and ability to
205hydrolyze certain substrates, we concluded that it was a carboxypeptidase, functioning by hydrolyzing
206ester linkages (82). Denise Baxter had already hinted that carboxypeptidase might work in this way (87).

207

208In some quarters (for example the legendary German brewing professor, the true gentleman Ludwig
209Narziss) this discovery seemed to explain a great deal and the concept was embraced wholeheartedly.
210There were others, however, who saw no reason to invoke the existence of such an enzyme (169).
211Undaunted, we carried on with our investigations, investigating the switching on of additional quantities
212of the enzyme during germination (62), the relationship between levels of the enzyme and the quality of
213different barleys (138) and getting a feel for the true relationships between the so called gums (water-
214soluble β -glucans) and hemicelluloses (the water-insoluble ones) (8, 63). I was also struck by the
215imperative that *Trichoderma* must have a β 1-3-glucanase if it was going to comprehensively convert the
216mixed linkage β -glucan all the way to glucose. Thus I made a study of an exo- β 1, 3-glucanase from the
217fungus (7).

218

219As part of the study of glucan degradation, we also made forays into endo- β -glucanase (64) and
220proposed an alternative assay for the enzyme (140). As a kid I had been struck by a tube of an odd
221substance in my Merit Chemistry set, namely Congo Red. Now, two decades later, I worked out what it
222was for: it specifically stains β -glucan! So we made agarose gels in Petri dishes containing β -glucan-Congo
223Red complexes and punched holes in them. Into the holes we put our enzyme solution. Overnight the
224enzyme would diffuse into the gel, break down the glucan and thus remove the red color. The diameter
225of the clear zones around the holes was logarithmically proportional to how much enzyme is present. I
226was rather proud of the method, but nobody has ever seemed to use it other than us. (You can't get too
227sensitive in this business.)

228

229Yeast makes dimethyl sulfide

230

231The second project that I muscled in on was being undertaken by a very slight red haired lad called Brian
232Anness, a Yorkshireman with an excellent talent as a cricketer. He had been trying to unravel the mystery
233of whether or not yeast makes dimethyl sulfide (DMS). Work from Allied Breweries' Kiwi Bob Anderson,
234working in conjunction with Roy Parsons and Harry White at Bass, had indicated that yeast does indeed
235make DMS, in addition to the amount that was released by thermal processes in the brewhouse, notably
236wort boiling (see 2 and 45 for reviews of the whole DMS story). White, another Yorkshireman and one
237who had arrived at Nutfield from a post-doc at UC Los Angeles, suggested that there were two
238precursors of DMS in malt: one called HADMS which released DMS upon strong heating in alkali (hence
239the HA) and one called 'active HADMS' which is converted by yeast into DMS. The latter was present in

240significant amounts only after the curing stage of malting. He surmised that both were peptides
241containing S-methylmethionine. The aforementioned Chris Dickenson, by now working with Allied
242Breweries in Burton and still Morris Dancing, concluded that the former substance was simply SMM and
243intimated that the latter substance was actually non-existent. Brian had his own evidence, however, that
244yeast could make DMS and indeed Richard Wilson and Chris Booer working in Howieson Rennie's team
245at BRF concurred. But nothing that Brian fed to yeast could be transformed into DMS, least of all SMM.

246

247And so to the day that Brian and I were sitting chewing over the quandary. I can see us now. He was
248sitting at his chair gazing out to the lake and the cricket pitch beyond; I was sitting on the desk with my
249back to the window swinging my legs as we chatted. At that point another great batsman, Brian's
250technical assistant Hamish Dunn, walked in holding a photocopy of a paper that he had been reading in
251the BRF library. It was by Zinder and Brock from the University of Wisconsin, Madison (172) and spoke of
252the reduction to DMS of dimethyl sulfoxide (DMSO). Nestling in the table of organisms (mostly bacteria)
253that the authors had listed was yeast, *Saccharomyces cerevisiae*, showing that it had a seemingly minor
254capability to get the job done. Brian and I looked at one another and wasted no time in looking into this.

255

256Brian grew yeast on simple media that contained added DMSO and found that DMS was produced.
257Meanwhile he took suspensions of yeast and incubated them with DMSO and showed that they
258produced DMS. And I smashed open yeast, incubated the extracts with DMSO and NADPH and can see in
259my mind's eye all these years later the huge peak of DMS appearing on the print out (loads of paper in
260those days) from the gas chromatograph. DMSO was indeed the mystery substance (3, 46), and Brian
261went on to measure it in malt and he unearthed the conditions under which it was produced – which
262was indeed in the curing stage of malting (see Harry White's work mentioned earlier). I produced data

263that suggested that the enzyme was actually methionine sulfoxide reductase working on DMSO instead
264of its primary substrate (6).

265

266The redoubtable Acting Director, Dr. John Hudson, was at once excited (some extra puffs on the pipe) but
267also wary. "Good heavens, young man, DMSO is a bloody solvent in chemistry laboratories." However we
268were allowed to publish (3). In this first paper and the first publication on solubilase the head of the
269team insisted on having his name on the author list. When I became a head of section at BRF I refused to
270do this and at all subsequent stages in my career I have steadfastly avoided having my name on any
271publication to which I have not made a material contribution. I guess my publication list could have been
272many times longer but I would have gotten no satisfaction or pride from it. Certainly when I was Director
273of Research at BRF International years later I would have plenty to say about lots of projects leading to
274papers, but I don't think that gives any head of department a right to claim the glory.

275

276If people pooh-poohed the solubilase concept, then they were almost vitriolic about yeast making DMS.
277However Interbrew would report at the European Brewery Convention that 80% of the DMS in their beer
278came from labeled DMSO (136) and then Carlsberg produced mutants of yeast lacking in methionine
279sulfoxide reductase and which produced no DMS (113).

280

281[This wasn't to be the last time I took a look at the thioredoxin system. A formidable plant scientist, Bob
282Buchanan, at the University of California, Berkeley produced some evidence that the system may be
283involved in stimulating limit dextrinase, the enzyme that is barely functioning in conventional mashes
284because it is inhibited by attachment to a blocking agent (94). Try as we might, though, Craig Heisner and

285I could not demonstrate that the thioredoxin system could activate the enzyme, whereas the simple
286expediency of dropping the pH could (117). Throughout my career I have had a tendency to drift from
287topic to topic without necessarily dotting all the i's and crossing all the t's. This is one area that someone
288should go back to: take a proportion of a mash, drop its pH substantially to release limit dextrinase and
289then re-combine it with the main mash. A bit like decoction, but I digress. Apart from this study, my only
290contribution to the matter of starch degradation has been a review which threw up a number of areas
291that I would consider worthy of study had I not been heading in a twilight direction (30).]

292

293**Promotion**

294

295Around the time that Brian Anness and I were investigating DMSO, the nitrosamine problem raised its
296ugly head and Wainwright was moved over to take control of the studies on this headache. This freed up
297the position of Head of the Biochemistry and Biophysics team and I was invited to take that role. This
298meant that I was put in charge of a gifted group of scientists, including the excellent Denise Baxter who
299might fairly have expected to be given the role herself on the basis of years of service. Straightaway,
300though, I busied myself in looking at the team's productivity, which was supposed to include work on
301foam, but in which area the output had been somewhat lackluster. However my eagerness to get into
302the role coupled with their ability meant that for two of the team we were to embark on a period of
303some success.

304

305**Bubbles**

306

307Philip Slack is a loveable guy from Swindon, a chap who had the habit of wandering around in deep
308thought before suddenly hitting upon a whiz of an idea. In the case of his new focus on foam, however, I
309am not sure who came up with the idea of hydrophobic proteins, whether it was he or I, but it certainly
310was a heck of a way to launch into a new research area. The concept for the new foam project was
311simple: it might be anticipated that hydrophobic, water-hating polypeptides would prefer to head to and
312linger in bubble walls than stay in the watery environment of beer. Phil fractionated the proteins from
313barley and from beer by hydrophobic interaction chromatography and found that those with the most
314amphipathic character were indeed the ones with the most foam-stabilizing capability (155).

315

316As regards the idea for the other main foam project of the time, then I definitely know it was mine. It
317was late one Friday and I was sitting in the library at Lyttel Hall doodling and contemplating how to
318measure how much foam sticks to a beer glass. You do, don't you? Within five minutes I had reasoned
319that you could produce foam, have it stick to glass, then recover it from the glass as a solution and
320measure how much protein is in the solution. The more protein in that liquid, the more had been
321sticking to the glass. I collared Gordon Jackson before he left for the day, told him my idea and in the
322course of a very few weeks his steadfastness in the lab and our verbal interchanges (I talk more than he
323does!) led to the Lacing Index method (120), which we used to survey the impacts of various beer
324components on cling (52). Hilary Martin wondered whether we should call the units of lacing "Klingons".

325

326In those days all papers went through the desk of John Hudson, who was a stickler for grammar. Many a
327paper he ripped up (metaphorically), demanding a re-write. On this occasion, however, after 3 or 4

328weeks he said to me “I have read it, re-read it and read it yet again. And I can’t find anything wrong with
329it. Now that can’t be right, can it? So you’d best write it again.” It’s the only paper (120) that I ever
330thanked him for input to in the acknowledgements at the end! In fact, I believe my most cited paper ever
331was the review on foam that I wrote around that time (12). I also contributed another review later (20).

332

333Radical stuff

334

335By now we had a new Director-General at BRF, Professor Bernard Atkinson, who I immediately liked
336immensely as a person, who was undoubtedly the brightest intellect I ever worked with, but who had a
337very strange habit in the paper clip breaking department and somewhat of a brusque way of dealing
338with staff. It was Bernard who insisted that I went on a course at his old establishment, the University of
339Manchester Institute of Science and Technology, which was very much of a chemical engineering
340persuasion. However one presentation captured my imagination and this was on oxygen. Not only did it
341detail the impact of oxygen on rates of fermentation, but it also introduced me to the matter of oxygen
342radicals. Was this, I wondered, the clue to achieving enhanced flavor stability in beer? Was it oxygen
343radicals as opposed to ground state oxygen itself that was responsible for the deterioration reactions
344that damage wort and beer?

345

346That presentation had referred to the presence in aerobic organisms of enzymes that protect against
347such reactive oxygen species, so I came back to Nutfield to work on one of these. (At that time, and
348indeed for some while longer at my next employer, I still found time to work at the bench.) There
349followed the first significant study of the enzyme superoxide dismutase in barley (11).

350

351Burton bound

352

353By now I had been at Nutfield for five years and was looking for the escape tunnel. I turned down the
354Research Manager's job at a prominent malting company and I toyed with one of the new biotech
355companies, Biogen, in Geneva but that was not right for me. And then I interviewed successfully for a
356new lectureship position at Imperial College in London, but that felt even worse. However I reasoned
357that I would take it and went in to tell Atkinson that I was leaving. He confirmed that I was indeed on my
358way out – but it would be to Bass, because their Research Director Tony Portno wanted me. (I had been
359up to Burton just the once, given a talk about our DMS work, had parried and thrust with Portno who
360did not believe the DMSO story, but seemingly I impressed him.) Thus it was to Bass in Burton in 1983. I
361was finally close enough to my beloved Wolverhampton Wanderers Football Club to get a season ticket!

362

363In the ten months I was at Bass before being promoted to Research Manager I spent quite a bit of time
364myself at the bench, as well as being the line manager for a small team comprising Roy Parsons, Roy
365Cope and David Pantry. My focus continued to be foam and I had the crazy notion of bumping up the
366foam potential of beer by adding extra protein. Apart from the obvious and perhaps mundane possibility
367of getting more out of the spent grains, I also took a look at a range of well-known whipping proteins and
368hit upon egg white (48, 49, 163). We patented it (50) but soon came to realize that it was of limited value
369when added to beers produced from anything like a respectable amount of malt and which already
370contained ample foaming potential. It was only with our range of beverages made using a bland alcoholic
371base that it showed real potential and indeed we used it in a product called Flamingo that had a pink

372hue, a strawberry flavor and a creamy head. However the product was short lived and we were
373concerned in any event about possible allergic reactions.

374

375One approach that we did successfully employ to enhance the foam of many of our beers was to include
376a proportion of the bitterness as post-fermentation bittering (the higher levels of the more foam-
377stabilizing isomers is the key to this approach) but also to add zinc. Addition of this agent at an order of
378magnitude higher than might be added to a fermenter is quite effective for rendering a quasi-solid and
379cling-able foam. Doubts about whether we were strictly allowed to make such additions, even though
380zinc was added globally into fermenters, led us to abandon the practice, though not before we had seen
381whether the higher addition rates made pre-fermentation would carry through to the beer. They didn't.
382Of course, the zinc saga was something we never published (although in one mega-analysis of beers by
383the Campaign For Real Ale the 2ppm stood out in our beers alone!). In light of the company changes
384induced by Thatcher's Beer orders that saw Bass morph into InterContinental Hotels, I saw no
385restrictions on me re-exploring the zinc notion in one of our studies much later – nobody else had
386seemed to cotton onto it during the intervening years (150).

387

388I did patent one other foaming invention: the concept of producing a foam stabilizing gas in situ (17). The
389demonstration experiment involved a beer containing the enzyme catalase and a glass rinse containing
390hydrogen peroxide. Pouring the beer into the freshly rinsed glass saw the extremely powerful enzyme
391convert the peroxide into oxygen and the foam not only grew and grew but it surged up above the rim of
392the glass and continued to grow whilst stabilizing into a solid mass that looked like a vast meringue atop
393the beer. We realized that this particular combination was not going to be the right one, but we thought
394the concept was pretty nifty!

396Roy Cope worked with me on the egg white project. I am not sure he would claim it to be his favorite
397study in his long and prestigious career in the lab which started in the regime of the legendary Cyril
398Rainbow. But we did develop a technique based on albumin (48) that we still use here in the States to
399analyze foam problems (see later). Roy was one of the best brains I ever worked with – versatile, highly
400practical: he once was drummer in a band that warmed up for The Swinging Blue Jeans. With others,
401including Paul Hegarty, we worked on some fairly innovative approaches to foam, including expert
402systems incorporating scanning electron microscopy (115), Roy and I, together with a new product
403development guy, Kim Butcher, took a look at how individuals' perception of beer flavor are heavily
404impacted by visual aspects of the product as well as by messages given to the consumer (77).

405

406Roy Parsons, too, was capable of doing first class research, although it was difficult to get him to
407concentrate on much more than DMS, on which he had been devoting his attention for many years. (He
408also had another life as a marriage guidance counsellor specializing in sex therapy, but that is a story for
409another day.) However I was very keen to explore further the concept of oxygen radicals in the context of
410staling and Roy and I worked closely to do a study that firmly pointed the finger for the first time at these
411entities as being the underlying trigger of staling in beer. I presented the work at the very first Brewing
412Congress of the Americas, in St Louis in September 1984 (68). Since then there has been a plethora of
413work using highly sophisticated technology to confirm that our premise was correct and that such
414reactive species need to be prevented from arising by minimizing transition metal ions as well as oxygen.
415The technology we used was simple indeed, with test tubes, thiobarbituric acid and a simple
416spectrophotometer. I remain convinced that the secret to good science is the intellect more so than
417fancy flashing lights.

419Meanwhile it was a delight to restore my collaboration with my old PhD supervisor Peter Large, through
420a series of studies funded through public agencies in the UK, but also through the co-authorship of my
421first book, one which took me back to my PhD and post-doc days (134). Our first PhD student was
422Richard Gibson (who would go on to a fine career with the confectionery company Rowntrees), who set
423to work to confirm my suggestion that the enzyme in yeast that reduces DMSO is a methionine sulfoxide
424reductase that uses the couple thioredoxin/thioredoxin reductase to feed it reducing power from NADPH
425(105, 106). It will be noted that I did not put my name on the papers as I really did not feel that my
426contribution was more than encouragement in that instance. However I did play a material role in three
427other elements of his work. We did labeling studies to show that even in beers that contained less DMS
428than was in the worts they were produced from, there was indeed ^{14}C in the DMS measured, illustrating
429the fact that yeast is making DMS even when simple DMS analysis suggests otherwise (108). Secondly we
430demonstrated that there is an inhibitor of DMS production present in worts, especially those made from
431darker pale ale malts (107). We confirmed that this inhibitor was methionine sulfoxide, so strictly
432speaking we were dealing with a preferred substrate that was delaying the ability of yeast to make DMS.
433We also demonstrated that DMSO reduction by yeast was very much dependent upon the amount of
434assimilable nitrogen available to the organism, with the greater incidence of DMS production at lower
435FAN levels, presumably being a consequence of the greater availability of reducing power under
436conditions when yeast growth was impaired (109).

437

438Much of what I was doing at Bass could, of course, not be published, including several internal advisory
439documents that were used by the company's breweries to help control processes and troubleshoot
440problems. Perhaps the most significant of these was the document that Parsons and I wrote on the

441strategy for controlling DMS levels in Carling Black Label, the flagship brand and biggest seller in our
442portfolio. It has to be said that it downplayed the yeast side of things (Tony Portno still did not believe it!)
443and that is quite reasonable. If you are controlling the SMM level in malt and are keeping all
444fermentation conditions constant, including the shape and size of the fermenter, then the DMSO to DMS
445route does indeed look after itself. It is the thermal degradation of SMM that generates the largest
446quantities of DMS and which needs to be controlled by attention to SMM levels in malt and the length
447and vigor of the boil and the duration and temperature in the whirlpool.

448

449One of our breweries, in Glasgow, was running well below target in the DMS level in their lager. Although
450it was technically a different brand (Tennents) it was still expected to match the Carling from Burton, so I
451was dispatched to the far North to sort them out. I came back with a flea in my ear, told by the Scots to
452prove why a given level of perception of DMS in the Tennents occurred at the lower concentration that
453they were running at. Roy Parsons hit upon phenylethanol and phenylethylacetate as agents that mask
454the perception of DMS and these were at significantly lower levels in Tennents than in Carling (116). The
455reason for this was that the Scots were fermenting at a temperature lower than the Group standard!

456

457**The real world - and back to BRF**

458

459Tony Portno was insistent that I needed to have the smooth edges of an ivory tower persona knocked off,
460so off I went to be the QA Manager at the Preston Brook brewery in succession to Harry White. I
461managed to keep my hand in on the research front by continuing my interactions with Peter Large. There
462were two successive PhD students working on oxidation issues, notably furthering the studies on

463superoxide dismutase, catalase and peroxidases. These were Simon Clarkson and, rather later, Chris
464Antrobus (4-5, 76, 78, 96-99). Simon went on to Whitbread and died tragically young.

465

466Preston Brook was somewhat anarchic (42), so I was soon itching to get back to research as a fulltime
467activity. It was a relief, then, to accept the position of Director of Research back at BRF and to become
468part of the team (Atkinson, Derek Laws, Alastair Macleay and myself) that transformed the organization
469to BRF International. In this role I was obviously involved in all of the research output of BRFI, but I
470steadfastly refused to stamp my name on anything unless the project had more of my input than the
471customary oversight, nudging in the right direction, pressure on those who needed a bit more pushing
472and Hudson-like critiquing of papers. The majority of the scientists in a staff of around 100 of course
473needed very little pushing and we had outstanding folks in the various teams, including John Hammond
474pioneering the government acceptance of genetically modified yeast and Bill Simpson with his work on
475the impact of bitterness substances and later his development of flavor substances trapped in
476cyclodextrins. Bill and I had a blistering row when he announced his intention to take that invention
477private, but we got over it. There was Nigel Davies doing excellent work on malt and Robert Muller
478effectively pursuing various areas in the biochemical field. And many more.

479

480Some projects, however, would not have happened without my ideas and those were the ones that
481resulted in papers featuring my name.

482

483In foam we developed a method for quantifying the hydrophobic polypeptides, which involved
484measuring the protein content of beer before and after passage through tiny columns of phenyl

485sepharose, the difference reflecting the amount of material that adsorbed to the column and which,
486accordingly, was hydrophobic (19). I have to say that I was never desperately happy with the procedure,
487as it involved subtracting two largish numbers to generate a smaller one, with those inherent
488inaccuracies. However others, including my friend Graham Stewart, did use the procedure to great effect
489and, indeed, BRF International commercialized the concept through a Dutch company.

490

491I also felt it timely to re-visit the solubilase saga and set Joanne Moore (who was in Mike Proudlove's
492Malt and Wort Production team) on to the task of firming up the identification of the enzyme. I will
493admit to being a much less tolerant person in those days (for sure, I should have been kinder to Mike). I
494recall well the unnecessarily negative way in which I received Joanne's news that she had found not one
495solubilase peak on gel permeation chromatography but four. It was with skepticism that I suggested the
496necessary studies to take a further look at these supposed four fractions, but Joanne, with input from a
497temporarily-employed scientific whiz called Danny McKillop, came up with the scenario that there were
498indeed multiple enzymes that would solubilize β -glucan: a carboxypeptidase, a pentosanase and two
499separate esterases (83). In collaboration with Paul Kroon in Gary Williamson's lab at the Institute of Food
500Research (IFR) in Norwich, we produced evidence that one of these enzymes is likely a ferulic acid
501esterase (146).

502

503**I love you, California – and back to bubbles**

504

505Once Bernard Atkinson retired from Lyttel Hall I quickly became disenchanted with what I saw happening
506around me in the new regime. It was therefore exciting to be confronted with the right academic

507challenge at the right time, namely the new Anheuser-Busch Endowed Professorship in Malting and
508Brewing Sciences at UC Davis. My wife Diane and I debated long and hard the pro's and con's but the
509decision was finally made and early in 1999 we moved the family thousands of miles for my dream job.

510

511I inherited a dismal and grossly under equipped laboratory but, thanks to the generosity of Anheuser-
512Busch, Sierra Nevada, Coors and others, we were able to progressively build up the facilities and the
513environment, culminating after a number of years in brand new buildings and state-of-the-art brewery
514and laboratories.

515

516In those initial days, though, in a few weeks of refurbishment when the old lab was shifted from being
517what I would categorize as "early fifties" to at least something that was late 1970's in standard, the first
518piece of experimental work was centered on perceptions of foam. I was mindful of the supposition of
519many that people's judgment of beer quality was strongly dictated by its head of foam but I was not
520aware of any published scientific study that actually gave concrete data in support of the premise. So,
521armed with a single beer, lots of glasses and a campus photographer called Sam Woo, I set about
522producing lots of images of beer with foams of diverse quality and analyzed people's impressions of
523them (24). (I would go on to do rather more of this later, with a student called John Smythe, who liked to
524break dance; 158, 160.) At this time Anheuser-Busch invited me to travel to St Louis as they intended
525loading a U-Haul with surplus laboratory equipment that I could drive the 1,992 miles back to California.
526(We would go from pycnometers to digital density meters almost overnight.) I was asked to present a
527talk whilst I was in Missouri and so I went through this study on foam that confirmed that even folks who
528confess to drinking beer straight out of the bottle do actually score higher those beers poured with a
529head as opposed to those that do not have a stable foam. When I finished, the top man, Doug

530Muhleman, inquired why the beer I had used had come from their major competitor. I had not said what
531the brand was but he recognized the impacts of reduced iso- α -acids!

532

533Once I had a half-decent lab in place – and supported by my steady and reliable part time right hand
534brewer and lab manager Candy Wallin - I recruited my first batch of students and embarked on some
535detailed studies on foam. One thing that happened was that suppliers of foam measuring
536instrumentation bombarded us with free equipment, in return for us using their instruments in our
537studies (119, 150, 166). However the Davis foam program started with a much simpler analytical tool.
538Greg Kapp, a New York lad, was charged with the task of ascertaining the relative importance to foam of
539the water-soluble proteins from barley (the albumins) as compared to polypeptides solubilized from the
540water-insoluble fraction of barley protein (the hordeins) which of course comprise the greater quantity. I
541continued to ponder whether foaming was essentially determined by hydrophobic character in a
542polypeptide, this being more important than the absolute identity of a given polypeptide, which at the
543time was focusing people's attention on Protein Z and, even more the case, Lipid Transfer Protein (LTP1).

544

545The first thing Greg developed was a simple shaking test with which we could compare the foaming
546properties of the various polypeptide fractions, some of which were available in only small quantities.
547Straightway Greg found that there was indeed foaming power in both the albumin and hordein-derived
548fragments and that if you denatured the polypeptides using heat or acid you both increased their
549hydrophobicity and increased their foaming potential (132). This was entirely predictable and was in
550keeping with what Bech had found at Carlsberg in that LTP1 as isolated from grain really wasn't a very
551good foaming protein but after boiling (a.k.a. denaturation) it became a strong foaming agent, on
552account of it being opened up to reveal the hydrophobic portion of the interior. It was also evident from

553our work that the foam was superior from the albuminoidal polypeptides. (We did try to develop; a
554flurochrome approach to assessing hydrophobic polypeptides but it wasn't very successful, 81)

555

556Next Greg simulated the protein degradation that occurs during barley modification by using a range of
557defined proteolytic enzymes. Intriguingly he showed that limited proteolysis of hordein by several of
558these enzymes caused an enhancement of foam performance, whereas some of the enzymes distinctly
559damaged the foam from the albumin (132). Of particular relevance was the observation that Proteinase
560A, the enzyme from yeast that Graham Stewart focused upon as being detrimental to the foam from
561beers produced through high gravity brewing techniques, destroyed the ability of hordein-derived
562polypeptides to stabilize foam and seriously depleted the foaming of the albumins.

563

564Greg's work was continued by a young Italian undergraduate, Cristian Milani. I reminded him that beer
565is, of course, not a pure protein solution but rather a "soup" of many different molecules, including
566diverse types of protein. What, then, were the foaming properties of mixtures of the isolated albumin
567and hordein fractions? In a nutshell the conclusions were that the albumins were indeed superior
568foaming polypeptides as compared to the hordeins but the presence of increasing quantities of the latter
569decreased the ability of albumin to stabilize foam (65). We hypothesized that there is a competition for
570places in the bubble wall and that if hordein-derived polypeptide squeeze out albumin then this is to the
571detriment of the net foam performance. In other words, the observed foam stability is impacted by
572competition between different polypeptides.

573

574 Soon after I arrived in Davis I agreed to accept into my laboratory a post-doc who came fully-funded from
575 Japan. Early in 2000 there was a knock on the door to signal that Makoto Kanauchi had arrived. It was
576 immediately obvious that he spoke not a word of English. Just a small problem – so I gave him a lab to
577 share with French Cameroon native, Jean-Pierre Biawa, formerly of BRi and VLB Berlin, who was with me
578 for a hugely enjoyable year (for me and I hope for him too) before he went on to do great things with the
579 Miller Brewing Company. In that time he gave Makoto a smattering of the English language, but Makoto
580 did learn to speak with a Cameroonian accent! Dr. Kanauchi and I retain our close collaboration all these
581 years and still do much research together.

582

583 Makoto made further studies on the model foaming system, showing inter alia that ethanol enhanced
584 the foaming potential of hydrolyzed hordeins but lessened that of albumins, that zinc had much more
585 impact on albumin-based foams and that for both types of protein foam stability was higher as the pH
586 was increased in the range 3.8-4.6 (55). Interestingly quite the opposite impact of pH on foam was seen
587 in beers adjusted to different pH's (80), highlighting that model systems may have their shortcomings.
588 [pH, generally, is not the simplest of topics but its impacts are far ranging, as addressed in 27 and 74.]

589

590 Meanwhile another of the initial intake of masters students, the guitar-playing Dave Lynch, focused on
591 the complexities of bubble nucleation. We devised a simple semi-quantitative technique for assessing
592 the extent of bubble formation, featuring the definitive nucleation sintered glass bead which is in a case
593 and guarded, a bit like the international prototype of the kilogram in the Bureau International des Poids
594 et Mesures in Sèvres, France (137)! Mathematical models were developed to explain the factors that
595 influenced the extent of foam formation, but it came as no surprise that the presence of a nucleation
596 site per se is a necessary pre-requisite, nor that the amount of carbon dioxide in the beer had a very

597substantial impact. I duly distilled my thoughts about the relative significance of physics and chemistry
598in determining the foaming properties of beer (31).

599

600Time was when I was convinced that foam negative materials, notably lipids and detergents, were
601primarily introduced into the beer at the point of dispense. Work we had performed at BRF International
602on lipid binding proteins had led me to believe that any lipid endogenously emerging through the
603brewing process was adsorbed onto such proteins and rendered harmless (147). That this was not the
604case first arose from work we had performed at BRi (101), but I set Jonathan Goldberg, who came to us
605in Davis from a first degree at Heriot-Watt University, on investigating further the extent to which foam
606performance in commercial beers is dictated by the level of proteins as opposed to the presence of
607foam-negative species (110).

608

609Jonathan approached the challenge in two ways. The first was based on the technique that we had used
610at BRi, assessing the extent to which the foam stability of a beer could be increased by passage of that
611beer through a Sepharose column to which a lipid binding protein (bovine serum albumin) had been
612attached. If the foam stability increased then this was indicative of the removal of foam-destabilizing
613lipid. Jonathan found that six out of ten beers examined displayed the presence of foam inhibitors.

614

615The second approach was a development of the technique that Roy Cope and I had first proposed in
6161987. The concept revolves around my old friend egg white. In the first instance albumin is added to the
617native beer. If this improves the foam stability it is indicative of an insufficiency of foaming polypeptide in
618the beer. Next, the egg white is added to a beer that has been passed through an ultrafiltration

619membrane that removes everything with a molecular weight greater than 1,000 – which would mean
620removal of protein, for instance, but retention in the ultrafiltrate inter alia of the bitter substances and
621alcohol. The foam observed after different rates of addition of albumin to this ultrafiltrate is compared
622to the foam when the same amount of egg white is added to a simple solution containing the same
623amount of ethanol. Superior foam performance is expected in the former case, because of the presence
624of materials like the iso- α -acids. However if the foam is superior in the simple ethanolic solution this
625indicates that there is something foam negative in the ultrafiltrate. Again, Jonathan was able to
626demonstrate using this technique that many beers do indeed contain foam-inhibitory material.

627

628Clues to the identity of these materials came later with the successive MS theses of Alex Combe and
629Justin Ang. In Alex's case it was a classic example of how the vision that one has in response to a certain
630hypothesis can be turned completely upside down! I suggested to New Orleans-born Alex (someone
631capable of eating gigantic amounts of frighteningly spicy food) that he take a look at the long-standing
632hypothesis of the renowned Laurence Bishop that during kilning there is a melding of foaming
633polypeptides with polysaccharides, leading to complexes that are particularly adept at stabilizing bubble
634walls. I proposed that he make extracts of a range of pale and specialty malts and compare their foam
635performance, predicting that the more colored malts, as dogma dictated, would display superior foam
636performance that we could then dissect in terms of finding the Bishop complexes. It was a somewhat
637worried Alex who hesitantly showed me his initial data which revealed that, whilst the likes of roast
638barley and black malt did indeed have excellent foam performance, the various caramel and crystal malts
639for the most part displayed pretty paltry performance. In depth analysis using the Cope-Bamforth-
640Goldberg ultrafiltration approach and also dilution curve approaches indicated that indeed there is
641certainly foam-negative material in all the malts tested, but this is swamped by the foam positives in the

642very dark malts. Furthermore the inhibitory material is much more exaggerated in the caramel malts as
643compared to pale malt (100).

644

645Justin Ang, a Chicago native, built upon Alex's work to use an old friend of a technique, thin layer
646chromatography, to reveal that there are various lipid species present in enhanced amounts in the
647particularly problematic malts, especially triglycerides and oxidized lipids (1). It seems that another
648dogma has been shot down – but too late for my book on how to solve foam problems (44)!

649

650Unraveling cell walls

651

652Makoto Kanauchi's main pursuit at Davis was to try to unravel the solubilase saga. Initially we took two
653tacks. The first saw us turning to my old friend *Trichoderma viride*. (When I first started working on it I
654used to call it *T. reesei*, but the man it was named for, Elwyn T. Reese, wrote to me from the Army
655research place in Natick to tell me that that name was warranted for only a small range of *T. viride*
656species – and not mine.) Since first using cellulase isolates from this organism to measure β -glucan in the
657late seventies, I had realized that it was capable of totally hydrolyzing barley β -glucan, so the question
658was, would it grow on it as a carbon source? And, if it would, I hypothesized that it would release
659enzymes in the sequence that it needed them. So how would it be if we presented the organism with cell
660walls per se? What was the sequence of enzyme development? From that we should be able to get clues
661about the cell wall structure and the order in which enzymes were needed to digest them, all the time
662holding to my central dogma that it was at least a two stage process: solubilization followed by hydrolysis
663of glucans. Makoto duly did the experiment and found that, yes, *T. viride* grows on cell walls and that

664arabinoxylan (pentosan) was solubilized before β -glucan. Seemingly the first enzyme to be released was
665actually a xylanase, and it was demonstrated that an esterase, carboxypeptidase, and endo- β 1-4-
666glucanase all preceded endo- β 1-3, 1-4-glucanase (121).

667

668The second approach was facilitated by the presence in Davis of a research group of the Novozyme
669company. Generously, their CEO, Glenn Nedwin, made available to us a range of highly purified enzymes
670that Makoto could use to dissect walls. Thus we showed that the most powerful effect was ascribable to
671a xylanase, further indicating that the glucan is somewhat trapped inside the pentosan in the cell wall
672(122, 123). There was some limited solubilase action due to esterases that remove ferulic acid and acetic
673acid from the arabinoxylan material – interestingly these enzymes seemed to smooth the fluffy surfaces
674of the cell walls as witnessed under an electron microscope. We duly came up with a model for the cell
675wall which featured a preponderance of pentosan on the outside of the wall, with the β -glucan
676concentrated inside (54). I was struck by the fact that Makoto had indeed confirmed the veracity of
677Joanne Moore's observations from several years previously (146).

678

679Two other Masters students delved further into these esterase enzymes. Bob Ward, who was my first
680ever MS student at UC Davis and who is now a Professor at Utah State (we recently edited a book
681together, 75), looked into acetylxylanesterase (168), while our charming Brazilian colleague Alberto Sun
682focused on this and also on feruloyl esterase, a study in which I collaborated once more with the IFR, in
683the shape of Craig Faulds (164). However it was two other students who fitted two key pieces into the
684puzzle.

685

686First was Anke Scheffler, one of three students who came to me to do their project within their studies at
687Weihenstephan. (Of the others, one found his reward in the shape of a bride, but the other we will come
688to later, in the form of Michaela Miedl.) Perhaps it was cynical of me to put a student from Germany to
689work on adjuncts and commercial enzymes, but Anke entered into the project with gusto. I proposed
690that she should use the BRF Mashing Bath to look at grists of 20% malt: 80% barley and with the addition
691of a range of enzymes. She found that, of course, β -glucanase additions had a major beneficial effect;
692however addition of a xylanase alone actually made matters worse in terms of an increase in viscosity
693and a decrease in filterability and extract yield. However the best performance of all came from mixtures
694of xylanase and glucanase (152). The most logical way to interpret this is in terms of xylanase releasing
695glucan trapped inside the wall (see above) which of course increases viscosity, but if glucanase was also
696present It could remove the glucan effectively, even more effectively than glucanase having to channel
697through the pentosan coat of the cell wall.

698

699The second student was Robert Kuntz, who climbs mountains and is now with MillerCoors. I asked him to
700look at the sequence with which the enzymes are synthesized as barley germinates. Contrary to what
701others had claimed, namely that xylanase was relatively late in its synthesis, Robert found that the very
702first enzyme to switch on was indeed a xylanase – and there was a later appearance of still more
703xylanase (133). This early turning on of some of the xylanase was entirely in keeping with our model.

704

705Notwithstanding this, it certainly does appear that there is significant retention of pentosan in malt and
706that this is not readily digested during mashing (unless an addition of heat tolerant enzymes is made).
707Substantial levels of pentosan were measured in beers by Kanauchi and I using a new procedure for
708pentosan that involved hydrolyzing the polymer using xylanase and measuring the xylose using xylose

709dehydrogenase (124). The most logical explanation of this survival of pentosan into beer is that there is
710an inhibitor of xylanase in grain (128, 129).

711

712Young-Tack Lee, who came to my lab on sabbatical from Kyungwon University in Korea, showed that it
713truly is the malting process that most effectively deals with β -glucan – a low temperature mash does not
714fully hack it (135).

715

716The other curiosity about cell wall degradation is that although there are enzymes present in malt that
717are in theory capable of completing the transformation of β -glucan into glucose, they do not seem to be
718primarily generating the ultimate end product and therefore oligosaccharides are present in sizeable
719amounts in beer (51). We proposed that the reason for this is that the enzyme likely to be most
720significantly employed to break down oligosaccharides actually has a very high K_m (low affinity) for the
721substrate (40, 125). The residual presence in beer of pentosans and β -glucan-derived oligosaccharides
722represent soluble fiber and putative prebiotics respectively (34, 51).

723

724**Getting fresh**

725

726A third major focus in our UC Davis program has been flavor instability and how to overcome it. The
727reality about studies on this topic is that they are extremely difficult to do and, for reasons eloquently
728aired by the late Morton Meilgaard (141), it is equally difficult to make a judgement about how reliable
729much of the work globally has been. An illustration of the problem comes from the work of my student

730 Sarah Bushnell (who became Mrs. Greg Kapp – there has been a history of match-making in the
731 Bamforth Lab). The aim was to see whether we could demonstrate any significant difference in flavor
732 stability in beer that had been treated with PVPP, which removes the polyphenols that some people
733 stress are important for flavor life. We also threw in sulfur dioxide as a separate study. As Meilgaard
734 explained, it is critical for trustworthy sensory reports to have properly conducted organoleptic trials. At
735 Davis we are blessed to have three experts in this area, Jean-Xavier Guinard, Michael O'Mahony and
736 Hildegard Heymann. In this instance Sarah worked with J-X to develop a trained and trustworthy panel
737 to evaluate the freshness of her various beers after storage. In the first instance we could find no
738 significant difference between the beers treated or not treated with PVPP (92). However the “kicker”
739 was in the work with SO₂. Although the average staling score was lower if SO₂ was added and higher if
740 the air level in the bottle was increased, in this actual study these differences were not statistically
741 significant. Now I am not at all saying that it is not important to keep O₂ levels as low as possible in the
742 finished beer and I am not implying that SO₂ is without benefit. All I am stressing concerns the statistical
743 significance of the reported data. It seems very easy for some people to report differences that suit their
744 prejudice, without endeavoring to demonstrate that those differences are absolutely meaningful.

745

746 We also posed an even more fundamental question: just how important is it to keep beer fresh? In other
747 words: does the customer care? And so Bill Stephenson (who came to me from Chicago with a first
748 degree in Economic History but he crammed chemistry in Hollywood) took a famous North American
749 lager and cooked it in an oven for a month. Then he took that beer (chilled) and the un-aged equivalent
750 into Sacramento and sought the opinion of tasters (161). He presented pairs of beers, identifying them
751 using different drip mats. When he put a fresh one and a stale one side by side on mats that showed the
752 name of the brand, there was an equal split in declared preference. When he did the same thing using

753glasses placed on plain white drip mats he got the same outcome. When he took the stale product in
754both glasses and put one on a mat giving the brand name and the other on a plain mat, there was a two-
755thirds preference for the one on the white mat. But when he put the fresh beer in both glasses, the one
756placed on the mat giving the brand displayed a 66% preference over the one placed on an unlabeled
757white mat. Our conclusion was that people make decisions primarily based on brand identity, but if a
758product falls short in a characteristic (in this case freshness) then they move away from it. I recall the
759phone call when we wrote up the paper from the head honcho of the company concerned, who didn't
760seem to be smiling when he said "why did you do that?"

761

762Confident that we were indeed studying a worthwhile topic, we started to investigate the relative
763importance of upstream oxidation (162), picking up from the work that I had been doing earlier with the
764likes of Peter Large, Paul Hughes, Robert Muller, Martin Walker, Geoff Buckee and Mike Walters (79, 84,
765167). It was all too apparent that oxygen could indeed be consumed in the brewhouse, notably in
766mashing, but I remained unconvinced that lipoxygenase was quite the culprit that several people had
767been insisting. From a theoretical perspective I had concluded that non-enzymic oxidation was at least as
768damaging (21).

769

770Indeed, Jean-Pierre Biawa did a fine piece of two substrate kinetic analysis on lipoxygenase in which we
771showed that the K_m for linoleic acid was really rather high, meaning that if this enzyme truly had
772importance it was much more likely to be at the very onset of mash mixing, when the enzyme was still in
773close proximity to the lipid-rich membranes of the embryo (88).

774

775The reality is that there is plenty of competition for the oxygen in a mash: an abundance of chemical
776events that are seeking to remove the oxygen (22, 25, 26, 32, 41). These include reactions with thiol
777compounds and polyphenols, the latter probably by way of the hydrogen peroxide produced in this
778oxidation and the intermediacy of peroxidase enzymes. The oxidized polyphenols cause the
779insolubilization of proteins by cross-linking. Relatively recently my collaboration with Makoto Kanauchi
780has thrown up two “new” enzymes not reported previously in a malting and brewing context: ascorbic
781acid peroxidase (127) and ascorbic acid oxidase (131) which can use ascorbic acid to scavenge peroxide
782and oxygen respectively. The latter enzyme is particularly intriguing as it is phenomenally heat tolerant,
783probably because it is relatively tiny. The truly interesting outcome of this work is that we have shown
784that additions of ascorbic acid to mashes enable ascorbic acid oxidase to scavenge oxygen, thereby
785leading to less thiol oxidation (as measured by more – SH groups left behind in the wort) and less
786polyphenol oxidation (assessed by higher levels of polyphenol in the wort). Those folk who insist that
787lipoxygenase in the malt and mash is important might care to see if ascorbic acid will preferentially divert
788oxygen away from that enzyme, leading to enhanced flavor stability. But it could just as readily be argued
789that the decreased oxygen level means less base material for the production of reactive oxygen species
790(32).

791

792Two other oxidases that we scrutinized were oxalate oxidase (130) and thiol oxidase (85). We were
793especially intrigued by the latter, notably the discovery that it is present in significant quantities in freshly
794kilned malt but that during 2-4 weeks of storage its levels decline to zero. We hypothesized that this is at
795least a part of the reason why malt needs to be stored prior to brewing. We speculated that if the
796enzyme is present it can catalyze the cross-linking of gel proteins leading to the sluggish separation of
797wort.

798

799Discussion of these various enzymes amongst all the others addressed in my teams over the years brings
800home to me how I am fundamentally an enzymologist at heart, as evidenced by a range of contributions
801intended to clarify the significance of these fascinating entities to the production of great beer (13,15,
80216, 37, 39, 47, 114)

803

804**Looking at beer**

805

806Mention of the contribution of polyphenol oxidation to beer color and haze development leads to a
807discussion of the limited work that we have performed on color and haze at UC Davis. With John Smythe
808I took a look at the issue of how reliably color is really measured on the basis of simple absorption of
809light at 430 nm (156). He took four well known beers – an Irish stout, an English ale, a European lager
810and a North American lager – and diluted all of them so that their color as determined in the standard
811ASBC method matched that of the palest product, the North American lager. Then we presented them to
812observers in a series of pairs, asking people to pick out the ones that looked different. When it came to
813the two lagers the folks could not pick them apart. But they could certainly differentiate between pairs in
814all other instances. The two ales were distinctly different in perceived color, with pinkish hues. The study
815reinforced my belief that the standard color approach has its drawbacks when trying to make a full
816interpretation of the precise “shade” of coloring in darker beers.

817

818As a teacher I must confess that color is one of the most difficult issues to get across – it is far more
819complex than you might imagine! To that end, Tom Shellhammer of Oregon State University and I made
820a fist at explaining it as simply as we could (154).

821

822We were prompted to look at haze by a major brewing company who had concerns in a year in which the
823barleys were running high in protein. They wanted to know if their existing tolerance level on haze was at
824the appropriate level or whether it might be over-reaching. Dylan Clark tackled this one (before he went
825off to teach at college – getting rather more chili peppers for hotness on *Rate My Professors* than I have
826ever received). Our conclusion was that the turbidity specifications in the industry appear to err a tad on
827the cautious side of practicality and might possibly be adjusted upwards to a small degree (95). Indeed,
828for reasons that we didn't explore further, it seemed that people actually prefer beer that had a level of
829turbidity just below the detection limit, as compared to rigorously bright product.

830

831Actually my first brush with haze came in my first stint with BRF. A brewery within one of our member
832companies was having an invisible haze problem – in which a beer registered high on analytical haze as
833gauged with a Radiometer haze meter (90° scatter) whilst appearing bright to the naked eye. John
834Hudson really hated the term invisible haze and urged us to come up with an alternative, so we
835suggested 'pseudo haze' but that has never caught on because folks like to talk about having 'invisible
836haze meters' (i.e. those that detect scattered light at a forward angle), No matter what we tried to call it,
837the fact was that we needed a centrifuge running at 100,000 x g to collect the tiny particles, which upon
838enzymic digestion proved to be largely starch, protein and β -glucan, suggesting that the problem was
839due to inadequately degraded starchy endosperm (53). Not long after joining Bass, my immediate boss
840Stuart Molzahn asked me to write an advisory note on the angle at which the group should be measuring

841haze. Twelve out of the thirteen breweries approved of my recommendation that it should be forward
842scatter. The exception was the Wellpark Brewery of Glasgow, who replied that they did not necessarily
843disagree with everything in my memorandum, for example I had spelled my name correctly.

844

845In pursuit of achieving colloidal stability of beer (23), Michaela Miedl, an Austrian student in that cohort
846from Weihenstephan who would go on to do her PhD with Graham Stewart at Heriot-Watt, was charged
847with the task of looking at the relative importance of time and temperature in the cold stabilization of
848beer and our conclusions clearly demonstrated that it is the lowness of the temperature that is far more
849important than the duration of the storage (142, 143).

850

851With Cale May and Christine Wright and my faculty colleague at Davis, Alyson Mitchell (who provided
852the polyphenol analysis), we compared “traditional” PVPP with a newer approach to removing the haze-
853forming tannic materials, showing the superiority of PVPP (145).

854

855Although, as I have said, I primarily consider myself to be an enzymologist, I would like to think that we
856have made a worthwhile contribution generally to the study of some of the more challenging aspects of
857beer quality, which can be broadly grouped under the heading “non-biological stability” (43).

858

859**Yeast**

860

861My friend Graham Stewart once joked that yeast was a bit of a mystery to me, yet over the years since
862our work on DMS we have dabbled with yeast in several ways, starting with a collaboration between
863Simon Clarkson and Peter Large in Hull and Chris Boulton and I at Bass. In this work we focused on the
864development of enzymes such as SOD and catalase in the protection of yeast against oxidative stress
865(99). I also critically discussed a frequently under-addressed issue, namely the extent to which variation
866in wort parameters can influence yeast performance (29).

867

868Latterly in Davis there have been a series of studies focused on the impact of yeast on flavor. Thus came
869Evan Miracle's investigation of sulfur volatile production on a commercial scale (144). The ongoing
870collaboration with Makoto Kanauchi fetched a short paper that presented evidence that the same
871enzyme (alcohol acetyl transferase) is responsible for producing the oxygen-containing esters but also
872the sulfur-containing thioesters (56). Furthermore the two of us scrutinized the enzymology of VDK
873removal by yeast and identified a selection of enzymes that serve the purpose of eliminating diacetyl,
874with differences between ale and lager strains (57). We also delved into the possibility that β -
875glucosidases from yeast might impact hop aroma (126).

876

877Beer's superiority over wine

878

879The longer I worked in California the more irritated I became by people claiming a perceived and implied
880superiority of wine over beer. To be sure that this was not merely an irrational frustration born of my
881blunt-spoken and perhaps intolerant heritage, I set a charming MS student, Christine Wright, on the task
882of working with me and our resident consumer expert Christine Bruhn on comparing the public

883perceptions of wine and beer (170, 171). It was clear that my feelings were justified and, allied to the
884findings of John Smythe and myself concerning much ignorance of people when it comes to beer (159), it
885was only too clear that there is a major education job to be done on the consumer in terms of
886positioning beer fairly as a drink of respectability, interest and healthfulness. In a series of articles and
887books I set about setting some facts straight (28, 33, 35, 36, 66), as well as delivering (with a succession
888of co-workers) some explicit data on the composition of beer in relation to health. This included an
889evaluation of whether beer really is a problem area when it comes to glycemic index (34).

890

891Working with my charming Irish colleague from the Department of Nutrition, Andy Clifford, we produced
892some realistic figures for the folic acid content of beers – lower than had been hitherto reported but still
893significant (148). With Michael DiPietro I illustrated just how important the in vitro test is when
894classifying beverages for their antioxidative capability, whilst at the same time showing that molecule for
895molecule, the antioxidant potential of beer is superior to that of wine (102). And with Troy Casey, son of
896Greg, we confirmed just how significant beer can be as a source of assimilable silicate (93).

897

898For the longest time individuals with gluten intolerance (Celiac disease) have been warned off the
899consumption of beer (38). However I was struck by the enormous losses of protein that generally occur
900during malting and brewing, together with the fact that many a beer is brewed with significant levels of
901grist materials that provide no problematic polypeptides. Surveying the literature for the state of the art
902when it comes to measuring problematic peptides, Lindsay Guerdrum (who has an identical twin sister)
903and I used the most reliable enzyme-linked immunosorbent assay that has so far become available to
904quantify the levels of such materials in a range of commercial brews. We found that a substantial
905proportion of beers – and not only the lighter ones – contained levels below the 20 ppm that represents

906the guideline laid down in Codex Alimentarius (111). For anyone doubting the wisdom of claiming a
907“normally” brewed beer to be low in gluten we were able to confirm the efficacy of the enzyme prolyl
908endoproteinase in removing any last trace of the undesirable sequences without jeopardizing foam
909(112).

910

911Of course another strategy for ensuring that there is no gluten or gliadin in beer is to produce beer from
912materials that are devoid of it. This is widely adapted with the production of products from the likes of
913sorghum, buckwheat, quinoa and so on. However I took this opportunity to explore something that
914stemmed back to something Bernard Atkinson had once insisted would represent the future for brewing.
915As a chemical engineer he was frankly irritated by the malting and brewing processes, insisting that all
916that water in and water out and the use of huge amounts of energy in heating and cooling processes was
917illogical – I think his exact word was “stupid”. He insisted that one day beer would be produced from a
918bland alcohol base with addition of color, foam and flavor from buckets. Sportingly, Jonathan Goldberg
919agreed to give it a shot in the lab and, armed with a bottle of Smirnoff vodka, he set about making an
920ersatz beer (118). Sensory guru Hildegard Heymann agreed to run the taste tests and we presented the
921product twice to a panel of beer tasters, the first time without comment and the second time after
922fessing up about the approach taken. They didn’t like the product much either time, but it was accepted
923as a beer and as an initial attempt that could clearly have been hugely improved upon. Most importantly
924the tasters did not seem to be fazed by the approach taken which did not contradict an earlier study
925(157).

926

927Another excellent student, Stephen Russell (who came to our attention from Doug Muhleman, whose
928son had been an on-line computer games pal of his) confirmed that the approach truly would be highly

929favorable from an environmental and all-manner-of-footprints basis (151). Les there be confusion, the
930very notion of the approach horrifies me.

931

932On a more traditional sensory platform, I also liaised with Dr. Heymann on the matter of hop aroma.

933Again it stemmed back to my conviction that brewers were shooting themselves in the foot by not

934articulating the diversity of aromas to be had from hops, unlike the wine folks who waxed lyrical about

935the notes delivered from their diverse grape varietals. And so Bryan Donaldson, with his ever-present

936bandana, worked with Hildegard to develop panels able to describe in interesting terms the aromas to

937be derived from various hops both as is and after dry hopping of a beer (103).

938

939**Wild stuff**

940

941And so I turn finally to Nick Bokulich and his astonishing productivity in the microbiological area of beer

942and wine in his time as a MS student with me and later as a PhD student with David Mills. Nick came to

943us from a liberal arts background, Hampshire College in Massachusetts, and proved himself to be a

944totally exceptional student. He had gained good practical grounding as a summer intern with Anderson

945Valley Brewing Company in Boonville CA and started their wild beer program (deliberately). His

946fascination with the topic led to a detailed assessment of the successive emergence of microbes through

947the life time of such products (89). I was also proud to co-author two reviews of the microbiology of beer

948with him (90, 91). At the moment Nick is lost to the world of brewing as he pursues an academic career

949in New York, but as I start to contemplate my life after brewing I fervently hope that somewhere out

950there is another such individual with the passion, ability and determination to grab hold of the baton.

951

952Living the dream

953

954I started this reminiscence with my home chemistry laboratory of the early 1960's. It was fun – making
955hydrogen sulfide to stink out the place from lumps of ferrous sulfide and various acids and even worse
956generating ammonia and tricking my aunt into sticking her nose into the flask. It was small wonder that
957my widowed mother was generally happy when I wasn't up to that sort of thing in doors, but rather was
958outside getting some exercise. And that for me was playing soccer with my brother and cousin, in which
959games I dreamed of being the Wolverhampton Wanderers goalkeeper. Although I had reasonable ability
960it remained that: a dream. Had I my time again I would have made it my business to put myself into a
961position where I might have made the vision a reality – even to the extent of knocking on the door of the
962club and asking for a trial. Years later, in 1985, when my playing career was in its final stages as keeper
963for a Bass Sunday League side was over, I **did** knock on the club's door and offered my services as a
964writer for their match day program. Within a week I had seen my first article published – and for 30-plus
965years I have been writing for them, for other professional clubs in UK and US, for magazines, for a
966website (www.wolvesheroes.com) and also a book about Wolverhampton Wanderers goalkeepers (what
967else!). My published output on soccer far exceeds that on brewing and beer!

968

969Thankfully, when it has come to my career in brewing, I have taken the opportunities as they have arisen
970and like to think that I have made the most of them, allowing me to rejoice in my current role which is
971the end of the journey. Sometimes it did not seem that the doors that I was invited to pass through were

972necessarily the correct ones, but generally it has proved to be so. The QA Manager position at Preston
973Brook was one such, giving me invaluable “real world” experience.

974

975Another valuable opportunity was afforded to me by John Hudson, who told me (I don’t think there was
976a choice in the matter) that I should become the recorder of the London Section of the (then) Institute of
977Brewing (IOB). The role entailed me journeying once a month into London and taking notes at the
978various meetings of the section, notably scribbling down the pearls of wisdom of guest speakers, at
979venues such as the famed Horseshoe Hotel pub on Tottenham Court Road and the London School of
980Economics. These notes were then published (anonymously) in the pages of the *Journal of the Institute*
981*of Brewing*. It was a marvelous introduction to this prestigious society, an organization that I have been
982proud to be a member of for over 35 years and to which I have contributed in diverse ways. This included
983being an examiner for the feared Paper II of the Diploma Exam, which was called the AME back in my
984time as the “interrogator” from 1988 to 1998. I chaired the Research Committee and the International
985Section, have been on the journal’s editorial board for many years and most recently have been truly
986proud to be the President of what is now the Institute of Brewing and Distilling. In 1984 I was the second
987recipient of the Cambridge Prize of the IOB (14). The first had been Chris Dickenson.

988

989It is hugely important to give back and thus I have always felt the need to get involved in the various
990societies. I am honored, then, to have been Editor-in-Chief of the *Journal of the American Society of*
991*Brewing Chemists* since 2000. ASBC were kind enough to give me the Award of Distinction in 2011 (45).
992Equally I have been privileged to be Honorary Professor at Nottingham University since 2006 and to have
993previously been Visiting Professor at Heriot-Watt University, who recently bestowed an Honorary D.Sc on
994me, for which I am so grateful.

995

996Which brings me to a final story. Years ago in England, with a degree of arrogance, my business card had

997a raft of post nominals after my name. I gave it to someone once, thinking they would be impressed.

998They returned their card to me, which simply gave their name after the prefix "Sir" and then underneath,

999"Ambassador to Norway". As my wife said: "I think simple cards are more effective, don't you, Charlie?"

1000But I can't resist pointing out that, with a PhD and two D.Sc post-nominals, I am strictly speaking "Doctor,

1001Doctor, Doctor". To most people, including my students I remain simply: "Charlie".

1002

1003

1004

1005

1006

1007

1008LITERATURE CITED

1009

1010 1. Ang, J.K., and Bamforth, C.W., Foam inhibitors from specialty malts. *J. Inst. Brew.*, 120: 193-200,

1011 2014

1012 2. Anness, B.J., and Bamforth, C.W., Dimethyl sulfide - a review. *J. Inst. Brew.*, 88: 244-252, 1982

1013 3. Anness, B.J., Bamforth, C.W., and Wainwright, T., The measurement of dimethyl sulfoxide in

1014 barley and malt and its reduction to dimethyl sulfide by yeast. *J. Inst. Brew.*, 85: 346-349, 1979

1015 4. Antrobus, C.J., Large, P.J., and Bamforth, C.W. Changes in the cationic isoenzymes of peroxidase

1016 during the malting of barley. I Tissue location studies. *J. Inst. Brew.*, 103: 227-231, 1997

- 1017 5. Antrobus, C.J., Large, P.J., and Bamforth, C.W., Changes in the cationic isoenzymes of peroxidase
1018 during the malting of barley. II The effect of gibberellic and abscisic acids. *J. Inst. Brew.*, 103: 233-
1019 237, 1997
- 1020 6. Bamforth, C.W., Dimethyl sulfoxide reductase of *Saccharomyces* spp. *FEMS Micro Lett*, 7: 55-59,
1021 1980
- 1022 7. Bamforth, C.W., The adaptability, purification and properties of exo-1,3- β -glucanase from the
1023 fungus *Trichoderma reesei*. *Biochem. J.*, 191: 863-866, 1980
- 1024 8. Bamforth, C.W., Enzymolysis of β -glucan. *Proc. Eur. Brew. Conv. Cong.*, Copenhagen, pp. 335-346,
1025 1981
- 1026 9. Bamforth, C.W., Barley β -glucans: their role in malting and brewing. *Brew. Dig.*, 57 (6): 22-27, 35,
1027 1982
- 1028 10. Bamforth, C.W., *Penicillium funiculosum* as a source of β -glucanase for the estimation of barley
1029 β -glucan. *J. Inst. Brew.*, 89: 391-392, 1983
- 1030 11. Bamforth, C.W., Superoxide dismutase in barley. *J. Inst. Brew.*, 89: 420-423, 1983
- 1031 12. Bamforth, C.W., The foaming properties of beer. *J. Inst. Brew.*, 91: 370-383, 1985
- 1032 13. Bamforth, C.W., The use of enzymes in brewing. *Brew. Guard.*, 114(9): 21-26, 1985
- 1033 14. Bamforth, C.W., Cambridge Prize Lecture: Biochemical approaches to beer quality. *J. Inst. Brew.*,
1034 91: 154-160, 1985
- 1035 15. Bamforth, C.W., Enzymes from the grist. *Brewer*, 72: 427-434, 1986
- 1036 16. Bamforth, C.W., Enzyme additions: requirements, optimization and potential problems. *Proc. Eur.*
1037 *Brew. Conv. Wort Symp.*, Maffliers, pp. 149-162, 1987
- 1038 17. Bamforth, C.W., Beer and other beverages dispensed with heads. UK Patent 2 167 313, 1988
- 1039 18. Bamforth, C.W., β -Glucan and β -glucanases in malting and brewing: practical aspects. *Brew. Dig.*,
1040 69 (5): 12-16, 21, 1994
- 1041 19. Bamforth, C.W., Foam: method, myth or magic? *Brewer*, 91: 396-399, 1995
- 1042 20. Bamforth, C.W., Bringing matters to a head: the status of research on beer foam. *Proc. Eur. Brew.*
1043 *Conv. Foam Symp.*, Amsterdam, pp. 10-23, 1999
- 1044 21. Bamforth, C.W., Enzymic and non-enzymic oxidation in the brewhouse; a theoretical
1045 consideration. *J. Inst. Brew.*, 105: 237-242, 1999
- 1046 22. Bamforth, C.W., The science and understanding of the flavour stability of beer: a critical
1047 assessment. *Brauwelt Int.* 17: 98-110, 1999
- 1048 23. Bamforth, C.W., Beer Haze. *J. Am. Soc. Brew. Chem.*, 57: 81-90, 1999
- 1049 24. Bamforth, C.W., Perceptions of beer foam. *J. Inst. Brew.*, 106: 229-238, 2000
- 1050 25. Bamforth, C.W., Making sense of flavor change in beer. *MBAA Tech. Quart.*, 37: 165-171, 2000

- 1051 26. Bamforth, C.W., Oxido-reduction processes and active forms of oxygen in aqueous systems.
1052 *Cerevisiae Biotech.*, 26: 149-154, 2001
- 1053 27. Bamforth, C.W., pH in brewing: an overview, *MBAA Tech Quart.*, 38: 1-9, 2001
- 1054 28. Bamforth, C.W., Nutritional Aspects of Beer – A Review. *Nut. Res.*, 22: 227-237, 2002
- 1055 29. Bamforth, C.W., Wort composition and beer quality in *Brewing Yeast Fermentation Performance*,
1056 *Second Edition*, K.A. Smart ed, Blackwell, Oxford, pp 77-85, 2002
- 1057 30. Bamforth, C.W., Barley and Malt Starch in Brewing: a general review. *MBAA Tech Quart*, 40: 89-
1058 97, 2003
- 1059 31. Bamforth, C.W., The relative significance of physics and chemistry for beer foam excellence:
1060 theory and practice. *J. Inst. Brew*, 110: 259-266, 2004
- 1061 32. Bamforth, C.W., A critical control point analysis for flavor stability of beer. *MBAA Tech Quart.*, 41:
1062 97-103, 2004
- 1063 33. Bamforth, C.W., *Beer: Health and Nutrition*, Blackwell, Oxford, 2004
- 1064 34. Bamforth, C.W., Beer, carbohydrates and diet. *J. Inst. Brew.*, 111: 259-264, 2005
- 1065 35. Bamforth, C.W., Beer as liquid bread. *MBAA Tech. Quart.*, 44: 15-18, 2007
- 1066 36. Bamforth, C., *Grape versus Grain*. Cambridge University Press, New York, 2008
- 1067 37. Bamforth, C. The ultimate enzymology: making beer. *Food Sci. Tech.*, 22(4): 12-14, 2008
- 1068 38. Bamforth, C.W., Producing gluten-free beer – an overview, in *The Science of Gluten-Free Foods*
1069 *and beverages*, E.K. Arendt and F. Dal Bello, eds, AACC International, St Paul MN, pp. 113-117,
1070 2009
- 1071 39. Bamforth, C.W., Current perspectives on the role of enzymes in brewing. *J. Cereal Sci.*, 50: 353-
1072 357, 2009
- 1073 40. Bamforth, C.W., The enzymology of cell wall breakdown during malting and mashing: an
1074 overview. *MBAA Tech. Quart.*, doi:10.1094/TQ-47-1-0309-01, 2010
- 1075 41. Bamforth, C.W., Flavour changes in beer: oxidation and other pathways, in E Decker, R
1076 Elias, D J McClements, eds, *Oxidation in foods and beverages and antioxidant*
1077 *applications. Vol 2: Management in different industry sectors*. Woodhead Publishing,
1078 Cambridge, pp. 424- 444, 2010
- 1079 42. Bamforth, C., *Beer is Proof God Loves Us*, FT Press, New Jersey, 2010
- 1080 43. Bamforth, C.W., 125th Anniversary Review: The non-biological instability of beer, *J. Inst. Brew.*,
1081 117: 488-497, 2011
- 1082 44. Bamforth, C.W., *Practical Guides for Beer Quality: Foam*. ASBC, St Paul MN, 2012

- 1083 45. Bamforth, C.W., Dimethyl sulfide – Significance, Origins and Control. *J. Am. Soc. Brew. Chem.*, 72:
1084 165-168, 2014
- 1085 46. Bamforth, C.W., and Anness, B.J., The role of dimethyl sulfoxide reductase in the formation of
1086 dimethyl sulfide during fermentations. *J. Inst. Brew.*, 87: 30-34, 1981
- 1087 47. Bamforth, C.W., and Barclay, A.H.P., Malting technology and the uses of malt. In *Barley Chemistry*
1088 *and Technology*, A.W. MacGregor and R.S. Bhatti, eds, American Society of Cereal Chemists, St
1089 Paul MN, pp. 297-354, 1983
- 1090 48. Bamforth, C.W., and Cope, R., Original approaches to improving the foam of beer. *Proc. Eur.*
1091 *Brew. Conv. Cong., Helsinki*, pp. 515-522, 1985
- 1092 49. Bamforth, C.W., and Cope, R., Egg albumen as a source of foam polypeptide in beer. *J. Am. Soc.*
1093 *Brew. Chem.*, 45: 27-32, 1987
- 1094 50. Bamforth, C.W., and Cope, R., Beer and other beverages and their manufacture. UK Patent 2 148
1095 322, 1987
- 1096 51. Bamforth, C.W., and Gambill, S.C., Fiber and putative prebiotics in beer. *J. Am. Soc. Brew. Chem.*,
1097 65: 67-69, 2007
- 1098 52. Bamforth, C.W., and Jackson, G., Aspects of foam lacing. *Proc. Eur. Brew. Conv. Cong., London*, pp.
1099 331-338, 1983
- 1100 53. Bamforth, C.W., and Jackson, G., Anomalous haze readings due to β -glucans. *J. Inst. Brew.*, 89:
1101 155-156, 1983
- 1102 54. Bamforth, C.W., and Kanauchi, M., A simple model for the cell wall of the starchy endosperm in
1103 barley, *J. Inst. Brew.*, 107: 235-240, 2001
- 1104 55. Bamforth, C.W., and Kanauchi, M., Interactions between polypeptides derived from barley and
1105 other beer components in model foam systems. *J. Sci. Food Agric.*, 83: 1045- 1050, 2003
- 1106 56. Bamforth, C.W., and Kanauchi, M., Use of novel assays to indicate that O-esters and S-esters are
1107 produced by the same enzyme in brewing yeast. *FEMS Micro. Lett.*, 228: 111-113, 2003
- 1108 57. Bamforth, C.W., and Kanauchi, M., Enzymology of Vicinal Diketone Reduction in Brewer's Yeast, *J.*
1109 *Inst. Brew.*, 110: 83-93, 2004
- 1110 58. Bamforth, C.W., and Large, P.J., Solubilization and partial purification of N-methylglutamate
1111 dehydrogenase from *Pseudomonas aminovorans*. *Biochem. Soc. Trans.* 3: 1066-1069, 1975

- 1112 59. Bamforth, C.W., and Large, P.J., Solubilization, partial purification and properties of N-
1113 methylglutamate dehydrogenase from *Pseudomonas aminovorans*. *Biochem. J.*, 161: 357-370,
1114 1977.
1115 60. Bamforth, C.W., and Large, P.J., The molecular size of N-methylglutamate dehydrogenase of
1116 *Pseudomonas aminovorans*. *Biochem. J.*, 167: 509-512, 1977
1117 61. Bamforth, C.W., and Large, P.J., The kinetic mechanism of N-methylglutamate dehydrogenase
1118 from *Pseudomonas aminovorans*. *Biochem. Soc. Trans.*, 6: 193-195, 1978
1119 62. Bamforth, C.W., and Martin, H.L. The development of β -glucan solubilase during barley
1120 germination. *J.Inst.Brew.*, 87: 81-84, 1981
1121 63. Bamforth, C.W., and Martin, H.L., β -Glucan and β -glucan solubilase in malting and mashing.
1122 *J.Inst. Brew.*, 87: 365-371, 1981
1123 64. Bamforth, C.W., and Martin, H.L., The degradation of β -glucan during malting and mashing: the
1124 role of β -glucanase. *J. Inst. Brew.*, 89: 303-307, 1983
1125 65. Bamforth, C.W., and Milani, C., The foaming of mixtures of albumin and hordein protein
1126 hydrolysates in model systems. *J. Sci. Food Agric.*, 84: 1001-1004, 2004
1127 66. Bamforth, C.W., and Murphey, L.J., Beer and Health, in *Beer Steward Handbook*, S. R. Holle, R.
1128 Klimovitz, L. Larson, K. Ockert, and S. Presley, eds. Master Brewers Association of the Americas,
1129 ST Paul MN, pp. 193-201, 2011
1130 67. Bamforth, C.W., and O'Connor, M.L., The isolation of pleiotropic mutants of *Pseudomonas*
1131 *aminovorans* deficient in the ability to grow on methylamine and an examination of their
1132 enzymic constitution. *J. Gen. Micro.*, 110: 143-149, 1979
1133 68. Bamforth, C.W., and Parsons, R., New procedures to improve the flavor stability of beer. *J. Am.*
1134 *Soc. Brew. Chem.*, 43:, 197-202, 1985
1135 69. Bamforth, C.W., and Quain, D.E., Enzymes in brewing and distilling. In *Cereal Science and*
1136 *Technology*, G.H. Palmer, ed, Aberdeen University Press, Aberdeen, pp. 326-366, 1989
1137 70. Bamforth, C.W., and Quayle, J.R., Hydroxypyruvate reductase activity in *Paracoccus denitrificans*.
1138 *J. Gen. Micro.*, 101: 259-267, 1977
1139 71. Bamforth, C.W., and Quayle, J.R., The dye-linked alcohol dehydrogenase of *Rhodopseudomonas*
1140 *acidophila*. *Biochem. J.*, 169: 677-686, 1978
1141 72. Bamforth, C.W., and Quayle, J.R., Aerobic and anaerobic growth of *Paracoccus denitrificans* on
1142 methanol. *Arch. Microbiol.*, 119: 91-97, 1978

- 1143 73. Bamforth, C.W., and Quayle, J.R., Structural aspects of the dye-linked alcohol dehydrogenase of
1144 Rhodopseudomonas acidophila. *Biochem. J.*, 181: 517-524, 1979
1145 74. Bamforth, C.W., and Simpson, W.J., Ionic equilibria in brewing. *Brew. Guard.*, 124 (12): 18-24,
1146 1995
1147 75. Bamforth, C.W., and Ward, R.E., Eds., *Oxford Handbook of Food Fermentations*, Oxford University
1148 Press, New York, 2014
1149 76. Bamforth, C.W., Boulton, C.A., Clarkson, S.P., and Large, P.J., The effects of oxygen on brewery
1150 process performance. *Proc. Inst. Brew. Conf., Aust. NZ Section*, pp. 211-219, 1988
1151 77. Bamforth, C.W., Butcher, K.N., and Cope, R., The interrelationships between parameters of beer
1152 quality. *Ferment*, 2: 54-58, 1989
1153 78. Bamforth, C.W., Clarkson, S.P., and Large, P.J., The relative importance of polyphenol oxidase,
1154 lipoygenase and peroxidases during wort oxidation. *Proc. Eur. Brew. Conv. Cong., Lisbon* pp.
1155 617-624, 1991
1156 79. Bamforth, C.W., Hughes, P.S., Muller, R.E., Walters, M.T., Antrobus, C.J., and Large, P.J., Oxidation
1157 in malting and brewing: assessment, implication and elimination. *Proc. Int. Brew. Tech. Conf.*
1158 *Harrogate*, pp. 267-276, 1996
1159 80. Bamforth, C., Kalathas, A., Maurin, Y. and Wallin, C., Some factors impacting beer foam. *MBAA*
1160 *Tech Quart*, 45: 332-336, 2008
1161 81. Bamforth, C.W., Kapp, G.R., and Smythe, J.E., The measurement of hydrophobic polypeptides in
1162 beer using the fluorochrome 1-anilino-8-naphthalenesulfonate. *Food Chem.*, 75: 377-383, 2001
1163 82. Bamforth, C.W., Martin, H.L., and Wainwright, T., A role for carboxypeptidase in the solubilization
1164 of barley β -glucan. *J. Inst. Brew.* 85: 334-338, 1979
1165 83. Bamforth, C.W., Moore, J., McKillop, D., Williamson, G., and Kroon, P.A. Enzymes from barley
1166 which solubilize β -glucan. *Proc. Eur. Brew. Conv. Cong., Maastricht*, pp. 75-82, 1997
1167 84. Bamforth, C.W., Muller, R.E., and Walker, M.D., Oxygen and oxygen radicals in malting and
1168 brewing: a review. *J. Am. Soc. Brew. Chem.*, 51: 79-88, 1993
1169 85. Bamforth, C.W., Roza, J.R., and Kanauchi, M., Storage of malt, thiol oxidase and brewhouse
1170 performance. *J. Am. Soc. Brew. Chem.*, 67: 89-94, 2009
1171 86. Bass, E.J., and Meredith, W.O.S., Enzymes that degrade barley gums. VII. Fractionation by column
1172 chromatography. *Proc. Am. Soc. Brew. Chem.*, pp 38-47, 1960

- 1173 87. Baxter, E.D., Purification and properties of malt carboxypeptidases attacking hordein. *J. Inst.*
1174 *Brew.* 84: 271-275, 1978
- 1175 88. Biawa, J.-P., and Bamforth, C.W., A two-substrate kinetic analysis of lipoxygenase in malt. *J. Cer.*
1176 *Sci.*, 35: 95-98, 2002
- 1177 89. Bokulich, N., Bamforth, C.W., and Mills, D.A. Brewhouse resident microbiota are responsible for
1178 multi-stage fermentation of American Coolship Ale. *PLoS ONE* 7(4): e35507.
1179 doi:10.1371/journal.pone.0035507, 2012
- 1180 90. Bokulich, N., Mills, D.A., and Bamforth, C.W., A review of molecular methods for microbial
1181 community profiling of beer and wine. *J. Am. Soc. Brew. Chem.* 70: 150-162, 2012.
- 1182 91. Bokulich, N.A., and Bamforth, C.W., The Microbiology of Malting and Brewing. *Micro. Mol. Biol.*
1183 *Rev.*, 77: 157-172, 2013
- 1184 92. Bushnell, S.E., Guinard, J.-X., and Bamforth, C.W., Effects of sulfur dioxide and
1185 polyvinylpyrrolidone (PVPP) on the flavor stability of beer as measured by sensory and
1186 chemical analysis. *J. Am. Soc. Brew. Chem.*, 61: 133-141, 2003
- 1187 93. Casey, T.R., and Bamforth, C.W., Silicon in Beer and Brewing. *J. Sci. Food. Ag.*, 90: 784-788, 2010
- 1188 94. Cho, M.J., Wong, L.H., Marx, C., Jiang, W., Lemaux, P.G., and Buchanan, B.B., Overexpression of
1189 thioredoxin h leads to enhanced activity of starch debranching enzyme (pullulanase) in barley
1190 grain. *Proc. Nat. Acad. Sci.*, 96: 14641-14646, 1999
- 1191 95. Clark, D.T., and Bamforth, C.W., Realistic haze specifications for beer. *MBAA Tech. Quart.*, 44: 160-
1192 163, 2007
- 1193 96. Clarkson, S.P., Large, P.J., and Bamforth, C.W., Purification of a cyanide-sensitive superoxide
1194 dismutase from soy beans: a food-compatible enzyme preparation. *J. Sci. Food. Agric.* 48: 87-97,
1195 1989
- 1196 97. Clarkson, S.P., Large, P.J., and Bamforth, C.W., Oxygen-scavenging enzymes in barley and malt and
1197 their effects during mashing. *J. Inst. Brew.*, 98: 111-115, 1991
- 1198 98. Clarkson, S.P., Large, P.J., and Bamforth, C.W., A two-substrate kinetic study of peroxidase
1199 cationic isoenzymes in barley malt. *Phytochem.*, 31: 743-749, 1992
- 1200 99. Clarkson, S.P., Large, P.J., Hegarty, P.K., and Bamforth, C.W., Oxygen radicals - their influence on
1201 process performance and product quality. *Proc. Eur. Brew. Conv. Cong., Zurich*, pp. 267-274, 1989

1202 100. Combe, A.L., Ang, J.K., and Bamforth, C.W., Positive and negative impacts of specialty
1203 malts on beer foam: A comparison of various cereal products for their foaming properties. *J. Sci.*
1204 *Food Ag.*, 93: 2094-2101, 2013
1205 101. Dickie, K.H., Cann, C., Norman, E.C., Bamforth, C.W., and Muller, R.E., Foam-negative
1206 materials. *J. Am. Soc. Brew. Chem.*, 59: 17-23, 2001
1207 102. DiPietro, M.B., and Bamforth, C.W., A comparison of the antioxidant potential of wine
1208 and beer. *J. Inst. Brew.*, 117: 547-555, 2011
1209 103. Donaldson, B.A., Bamforth, C.W., Heymann, H., Sensory Descriptive Analysis and Free-
1210 Choice Profiling of Thirteen Hop Varieties as Whole Cones and After Dry Hopping of Beer. *J. Am.*
1211 *Soc. Brew. Chem.*, 70: 176-181, 2012
1212 104. Forrest, I.S., and Wainwright, T., The mode of binding of β -glucans and pentosans in
1213 barley endosperm cell walls. *J. Inst. Brew.*, 83: 279-286, 1977
1214 105. Gibson, R.M., and Large, P. J., The involvement of thioredoxin and thioredoxin reductase
1215 in the dimethyl sulphoxide reductase system of *Saccharomyces cerevisiae*. *FEMS Micro. Lett.* 26:
1216 89-94, 1985
1217 106. Gibson, R. M., and Large, P.J., The methionine sulphoxide reductase activity of the yeast
1218 dimethyl sulphoxide reductase system. *FEMS Micro. Lett.* 26: 95-99, 1985
1219 107. Gibson, R.M., Large, P.J., Anness, B.J., and Bamforth, C.W., The identity of an inhibitor in
1220 wort of dimethyl sulfoxide reductase from yeast. *J.Inst. Brew.*, 89: 215-218, 1983
1221 108. Gibson, R.M., Large, P.J., and Bamforth, C.W., The use of radioactive labeling to
1222 demonstrate the production of dimethyl sulfide from dimethyl sulfoxide during fermentation of
1223 wort. *J.Inst.Brew.*, 91:, 397-400, 1985
1224 109. Gibson, R.M., Large, P.J. , and Bamforth, C.W., The influence of assimilable nitrogen
1225 compounds in wort on the ability of yeast to reduce dimethyl sulfoxide. *J.Inst.Brew.*, 91: 401-
1226 405, 1985
1227 110. Goldberg, J.R., and Bamforth, C.W., Analyzing foam instability in commercial beers. *J.*
1228 *Am. Soc. Brew. Chem.*, 68: 57-62, 2010
1229 111. Guerdum, L.J., and Bamforth, C.W., Levels of gliadin in commercial beers. *Food Chem.*,
1230 129: 1783-1784, 2011

1231 112. Guerdum, L.J., and Bamforth, C.W. Prolamin levels through brewing and the impact of
1232 prolyl endopeptidase. *J. Am. Soc. Brew. Chem.*, 70: 35-38, 2012
1233 113. Hansen, J. Inactivation of MXR1 Abolishes Formation of Dimethyl Sulfide from Dimethyl
1234 Sulfoxide in *Saccharomyces cerevisiae*. *Appl. Environ. Microbiol.* 65: 3915-3919, 1999
1235 114. Hegarty, P.K., and Bamforth, C.W., The evaluation of commercial enzymes in brewing.
1236 *Ferment*, 2: 296-299, 1989
1237 115. Hegarty, P.K., Cope, R., Lee, A.H., and Bamforth, C.W., New procedures and expert
1238 systems for the analysis of foam problems. *Proc. Eur. Brew. Conv. Cong., Zurich*, pp. 553-560,
1239 1999
1240 116. Hegarty, P.K., Parsons, R., Bamforth, C.W., and Molzahn, S.W., Phenyl ethanol - a factor
1241 determining lager character. *Proc. Eur. Brew. Conv. Cong., Brussels*, pp. 515-522, 1995
1242 117. Heisner, C.B., and Bamforth, C.W., Thioresdoxin in barley: could it have a role in releasing
1243 limit dextrinase in brewery mashes? *J. Inst. Brew.*, 114: 122-126, 2008
1244 118. Heymann, H., Goldberg, J.R., Wallin, C.E., and Bamforth, C.W., A "beer" made from a
1245 bland alcohol base. *J. Am. Soc. Brew. Chem.*, 68: 75-76, 2010
1246 119. Hung, J.K.S., Wallin, C.E., and Bamforth, C.W., An evaluation of an automated procedure
1247 for measuring beer foam stability. *MBAA Tech. Quart.*, 42: 178-183, 2005
1248 120. Jackson, G., and Bamforth, C.W., The measurement of foam lacing. *J. Inst. Brew.*, 88: 378-
1249 381, 1982
1250 121. Kanauchi, M., and Bamforth, C.W., Growth of *Trichoderma viride* on crude cell wall
1251 preparations from barley. *J. Ag. Food Chem.*, 49: 883-887, 2001
1252 122. Kanauchi, M., and Bamforth, C.W., The release of β -glucan from the cell walls of the
1253 starchy endosperm of barley, *Cereal Chem.*, 78: 121-124, 2001
1254 123. Kanauchi, M., and Bamforth, C.W., Enzymic digestion of walls purified from the starchy
1255 endosperm of barley, *J. Inst. Brew.* 108: 73-77, 2002
1256 124. Kanauchi, M., and Bamforth, C.W., Use of Xylose dehydrogenase from *Trichoderma viride*
1257 in an enzymic method for the measurement of pentosan in barley, *J. Inst. Brew.*, 109: 203-207,
1258 2003
1259 125. Kanauchi, M., and Bamforth, C.W., The relevance of different enzymes for the hydrolysis
1260 of β -glucans in malting and mashing. *J. Inst. Brew.*, 114: 224-229, 2008

1261 126. Kanauchi, M., and Bamforth, C.W., β -Glucoside hydrolyzing enzymes from ale and
1262 lager strains of brewing yeast. *J. Am. Soc. Brew. Chem.*, 70: 303-307, 2012
1263 127. Kanauchi, M., and Bamforth, C.W., Ascorbate peroxidase in malted barley. *J. Am. Soc.*
1264 *Brew. Chem.*, 71: 97-102, 2013
1265 128. Kanauchi, M., Chijimi, A., Ohnishi-Kameyama, M., and Bamforth, C.W., An investigation
1266 of two xylan-degrading enzymes and a novel xylanase inhibitor in malted barley. *J. Inst. Brew.*,
1267 119: 32-40, 2013
1268 129. Kanauchi, M., Ishikura, W., and Bamforth, C.W., β -Glucans and pentosans and their
1269 degradation products in commercial beers. *J. Inst. Brew.*, 117: 120-124, 2011
1270 130. Kanauchi, M., Milet, J., and Bamforth, C.W., Oxalate and Oxalate Oxidase in Malt. *J. Inst.*
1271 *Brew.*, 115: 232-237, 2009
1272 131. Kanauchi, M., Simon, K.J. , and Bamforth, C.W., Ascorbic acid oxidase in barley and malt
1273 and its possible role during mashing. *J. Am. Soc. Brew. Chem.*, 7: 30-35, 2014
1274 132. Kapp, G.R., and Bamforth, C.W., The foaming properties of proteins isolated from barley.
1275 *J. Sci. Food Agric.*, 82: 1276-1281, 2002
1276 133. Kuntz, R.J., and Bamforth, C.W., Time Course for the development of Enzymes in Barley.
1277 *J. Inst. Brew.*, 113: 196-205, 2007
1278 134. Large, P.J., and Bamforth, C.W., *Methylotrophy and Biotechnology*. Longman, Harlow,
1279 1988
1280 135. Lee, Y.T., and Bamforth, C.W., Variations in Solubility of Barley β -Glucan during Malting
1281 and Impact on levels of β -Glucan in Wort and Beer. *J. Am. Soc. Brew. Chem.*, 67: 67-71, 2009
1282 136. Leemans, C., Dupire, S., and Macron, J-Y. Relation between wort DMSO and DMS
1283 concentration in beer. *Proc. Eur. Brew. Conv. Cong.*, Oslo, pp. 709-716, 1993
1284 137. Lynch, D.M., and Bamforth, C.W., Measurement and Characterization of Bubble
1285 Nucleation in Beer. *J. Food Sci.*, 67: 2696-2701, 2002
1286 138. Martin, H.L., and Bamforth, C.W., The relationship between β -glucan solubilase, barley
1287 autolysis and malting potential. *J. Inst. Brew.*, 86: 216-221, 1980
1288 139. Martin, H.L., and Bamforth, C.W., An enzymic method for the measurement of total and
1289 water-soluble β -glucan in barley. *J. Inst. Brew.*, 87: 88-91, 1981
1290 140. Martin, H.L., and Bamforth, C.W., Application of a radial diffusion assay for the
1291 measurement of β -glucanase in malt. *J. Inst. Brew.*, 89: 34-37, 1983

1292 141. Meilgaard, M., Effects on flavor of innovations in brewery equipment and processing: a
1293 review. *J. Inst. Brew.* 107: 271-286, 2001
1294 142. Miedl, M., and Bamforth, C.W., The relative importance of temperature and time in the
1295 cold conditioning of beer. *J. Am. Soc. Brew. Chem.*, 62: 75-78, 2004
1296 143. Miedl, M., Garcia, M.A., and Bamforth, C.W., Haze formation in model beer systems. *J.*
1297 *Ag. Food Chem.*, 53: 10161- 10165, 2006
1298 144. Miracle, R.E. Ebeler, S.E., and Bamforth, C.W., The measurement of sulfur-containing
1299 aroma compounds in samples from production-scale brewery operations. *J. Am. Soc. Brew.*
1300 *Chem.*, 63: 129-134, 2005
1301 145. Mitchell, A.E., Hong, Y.-J., May, J.C., Wright, C.A., and Bamforth, C.W., A comparison of
1302 Polyvinylpolypyrrolidone (PVPP), Silica Xerogel and a Polyvinylpyrrolidone (PVP)-silica co-product
1303 for their ability to remove polyphenols from beer. *J. Inst. Brew.* 111: 20-25, 2005
1304 146. Moore, J., Bamforth, C.W., Kroon, P.A., Bartolome, B., and Williamson, G. Ferulic acid
1305 esterase catalyses the solubilization of β -glucans and pentosans from the starchy endosperm cell
1306 walls of barley. *Biotech. Lett.*, 18: 1423-1426, 1996
1307 147. Onishi, A., Canterrane, E., Clarke, D.J., and Proudlove, M.O., Barley lipid-binding proteins:
1308 their role in beer foam stabilization. *Proc. Eur. Brew. Conv. Cong., Brussels.*, pp. 553-560, 1995
1309 148. Owens, J.E., Clifford, A.J., and Bamforth, C.W., Folate in beer. *J. Inst. Brew.*, 113: 243-248,
1310 2007
1311 149. Preece, I.A., and Ashworth, A.S., Cytolysis in germinating barley. II Preliminary study of
1312 enzyme relationships. *J. Inst. Brew.*, 56: 40-47, 1950
1313 150. Roza, J.R., Wallin, C.E., and Bamforth, C.W., A comparison between the instrumental
1314 measurement of head retention/lacing and perceived foam quality. *MBAA Tech. Quart.*, 43: 173-
1315 176, 2006
1316 151. Russell, S.T., Singh, R.P., and Bamforth, C.W., Alternative Paradigms for the Production of
1317 Beer. *J. Inst. Brew.*, 114: 349-356, 2008
1318 152. Scheffler, A., and Bamforth, C.W., Exogenous β -Glucanases and Pentosanases and their
1319 impact on mashing. *Enz. Micro. Tech.*, 36: 813-817, 2005
1320 153. Scott, R.W., Solubilization of β -glucan during mashing. *J. Inst. Brew.*, 78: 411-412, 1972

1321 154. Shellhammer, T., and Bamforth, C.W., Assessing color quality of beer, in *ACS Symposium*
1322 *Series 983* (eds CA Culver and RE Wrolstad), pages 192-202, American Chemical Society,
1323 Washington, DC, 2008
1324 155. Slack, P.T., and Bamforth, C.W., The fractionation of polypeptides from barley and beer by
1325 hydrophobic interaction chromatography: the influence of their hydrophobicity on foam stability.
1326 *J. Inst. Brew.*, 89: 397-401, 1983
1327 156. Smythe, J.E., and Bamforth, C.W., Shortcomings in Standard Instrumental Methods for
1328 Assessing Beer Color. *J. Am. Soc. Brew. Chem.*, 58: 165-166, 2000
1329 157. Smythe, J.E., and Bamforth, C.W., The effect of perceived beer history on reported
1330 preferences by sensory panels with different levels of training. *J. Inst. Brew.*, 108, 34-36, 2002
1331 158. Smythe, J.E., and Bamforth, C.W., The path analysis method of eliminating preferred
1332 stimuli (PAMEPS) as a means to determine foam preferences for lagers in European judges based
1333 upon image assessment. *Food Qual. Pref.*, 14: 567- 572, 2003
1334 159. Smythe, J.E., and Bamforth, C.W. An evaluation of the public understanding of beer and
1335 brewing. *MBAA Tech. Quart.*, doi:10.1094/TQ-46-1-0316-01, 2009
1336 160. Smythe, J.E., O'Mahony, M., and Bamforth, C.W., The Impact of the Appearance of Beer
1337 on its Perception. *J. Inst. Brew.* 108: 37-42, 2002
1338 161. Stephenson, W.H., and Bamforth, C.W., The impact of lightstruck and stale character in
1339 beers on their perceived quality: A Consumer Study. *J. Inst. Brew.*, 108: 406-409, 2002
1340 162. Stephenson, W.H., Biawa, J.-P., Miracle, R.E. and Bamforth, C.W., Laboratory-scale
1341 studies of the impact of oxygen on mashing, *J. Inst. Brew.*, 109: 273- 283, 2003
1342 163. St John Coghlan, D., Woodrow, J., Bamforth, C.W., and Hinchliffe, E., Polypeptides with
1343 enhanced foam potential. *J. Inst. Brew.*, 98: 207-213, 1992
1344 164. Sun, A., Faulds, C.B., and Bamforth C.W., Barley contains two cationic acetylxylan
1345 esterases and one anionic feruloyl esterase. *Cereal Chem.*, 82: 621-625, 2005
1346 165. Waites, M.J., and Bamforth, C.W., The determination of ethanol in beer using a
1347 bioelectrochemical cell. *J. Inst. Brew.*, 90: 33-36, 1984
1348 166. Wallin, C.E., DiPietro, M.B., Schwarz, R.W., and Bamforth C.W., A comparison of three
1349 methods for the assessment of foam stability of beer. *J. Inst. Brew.*, 116: 78-80, 2010
1350 167. Walters, M.T., Hughes, P.S., and Bamforth, C.W., The evaluation of natural antioxidants in
1351 beer and its raw materials. *Proc. Inst. Brew. Conf. Asia Pac.*, pp. 103-109, 1996

1352 168. Ward, R.E., and Bamforth, C.W., Esterases in barley and malt. *Cereal Chem.*, 79: 681-686,
1353 2002
1354 169. [Wilhelmi, C.](#), and [Morgan, K.](#), The hydrolysis of barley beta-glucan by the cellulase EC
1355 3.2.1.4 under dilute conditions is identical to that of barley solubilase. [Carb. Res.](#) 330: 373-80,
1356 2001
1357 170. Wright, C.A., Bruhn, C.M., Heymann, H., and Bamforth, C.W., Beer and Wine Consumers'
1358 Perceptions of the Nutritional Value of Alcoholic and Non-alcoholic Beverages. *J. Food Sci.*, 73:
1359 H8-H11, 2008
1360 171. Wright, C.A., Bruhn, C.M., Heymann, H., and Bamforth, C.W., Beer Consumers'
1361 Perceptions of the Health Aspects of Alcoholic Beverages. *J. Food Sci.*, 73: H12-H17, 2008
1362 172. Zinder, S. H., and Brock, T. D. Dimethyl Sulphoxide Reduction by Micro-organisms. *J. Gen.*
1363 *Micro.* 105:335-342, 1978

1364

1365

1366Footnotes

1367 2. A D.Sc in the British University system is awarded for sustained and meaningful contribution
1368 to a field of study: one collates one's body of peer-reviewed work and the body is judged by
1369 a panel of D.Sc holders who determine whether that body of work represents a quality of
1370 delivery that warrants the degree.
1371 3. http://www.geniimagazine.com/magicpedia/Edwin_Dawes
1372