Maintaining the Quality Control of Beer

Kristina Habschied(✉) and Krešimir Mastanjević

Faculty of Food Technology Osijek, University of J.J. Strossmayer, F. Kuhača 18, 31 000 Osijek, Croatia
khabschi@ptfos.hr

Abstract. Today's brewing industries rely on continuous and reliable analytical methods in order to control the quality of produced beer, but also to respect the legislation related to beer quality. To achieve the wanted quality control it is important to bear in mind several things, such as size and age of the brewing industry, process automation and skills of the workers, availability of laboratory and technical evaluation of the laboratory equipment (calibration and general maintenance). Brewing process quality control involves a lot of indicators, but some of the most important are gravity of wort and beer, wort and beer pH, air injection into wort, yeast cell counts, yeast culture and propagation control, yeast viability, dissolved oxygen, carbon dioxide, sulfur dioxide, aerobic and anaerobic bacteria counts, microbiological culturing media, turbidity, color, alcohol, foam quality, sensory evaluation. Considering that beer can be packaged into cans, glass bottles, kegs or PET, many factors should be taken into an account. For example, PET packaging has the shortest storage time, 4 months in comparison to other kinds of packaging, such as kegs, cans or glass bottles. Sensory quality control evaluates the consumers' perception and often beer bought in store is not as the one tested in the brewery. However, the input of efforts and resources involved in beer quality control is continuous and important for the overall quality of beer.

Keywords: Beer · Quality insurance · Brewing industry

1 Introduction

1.1 The Importance of Beer Quality Maintenance

"Making great beer is hard. Making the same great beer every day is harder. Ensuring that your great beer is still great after packaging is harder still. And the hardest thing of all is ensuring that every customer gets the great beer you brewed, whether they drink it in your pub or another establishment, or from a glass, bottle or can…Our collective success is built on quality."

-Ken Grossman, Sierra Nevada Brewing Co.

The production of beer is a well known process. In modern brewing industry, due to the closed system, almost all errors are condensed to a minimum. However, certain mistakes can by-pass even the best maintenance and operational systems [1]. In a world on many choices of beer, uniformity is still the key to success. This means that the

H. Glavaš et al. (Eds.): OTO 2021, LNNS 369, pp. 435–446, 2022.
https://doi.org/10.1007/978-3-030-92851-3_33

consumers rely on certain beer quality characteristic for a chosen beer brand. They want consistency.

Even though quality control analysis seems standard and available in every brewery, this is not the case. In order to insure the consistent quality, breweries have to rely on many analytical methods, that are at times costly (chemicals, instruments) or require a skilled worker to conduct the analysis and interpret the results.

Quality control, its assurance and maintenance are important for several reasons: interest of other brewing companies and stakeholders; and quality tools can be utilized in solving current (potential) problems or improving unit operations [2]. Also, the aim of every corporation, in this case the brewery, is to enhance quality management as a part of the effort to:

- increase profits,
- improve the quality of both products and operations,
- prove environmental responsible behavior.

A quality management program can be implemented via several different systems [2]:

- Quality Management System (QMS) ISO 9001/2;
- Environmental Management System (EMS) ISO 14001;
- Health and Safety Management System (HSMS) OHSAS 18001:2007;
- Food Safety Management Systems (FSMS) ISO 22000:2005;
- Hazard Analysis Critical Control Points (HACCP).

There is a distinction between quality control and quality assurance. Namely, quality control monitors products to uncover any shortcomings or defects in order to allow the management to release or deny the product into sales. Quality assurance, on the other hand, attempts to improve and stabilize production (and associated processes) to avoid, or at least minimize, issues which led to the defect(s) in the first place.

Quality assurance assures the quality of the product (Beer) by systematic monitoring of raw materials, in process product, and end product.

Both should be implemented in: malting and brewing processes.

2 Quality Indicators

Quality maintenance must be identified in every brewery in order to the quality requirements whose standards, specifications and procedures are set by the brewing industry [1] and must follow the country's legislation. They mostly regard safety and quality upon production, packaging and selling [1].

2.1 Usual Quality Control Check-Points

Quality control and assurance should also be implemented in malting industry and usually they:

cover the barley check for suitability for malting and
prevent dead or unfit barley from entering the process.
Some of the typical barley and malt quality analysis involves [1]:

In barley

- color and odor
- % moisture and water sensitivity
- nitrogen content (total nitrogen) and protein
- % foreign seeds and materials
- absence of damage and fungal growth
- germinative capacity and germination energy
- barley type and variety
- barley
- kernel size

In malt

- time
- % kernel moisture
- kernel size
- temperature and flowrate of water and air
- color of malt
- protein, starch and enzymes levels
- sensory evaluation.

Quality maintenance in the brewery depends on several factors [1, 3]**:**

- size and age
- process complexity
- degree of automation
- styles of beer
- workforce size and degree of skill
- available in-house laboratory analyses – physical-chemical, microbiological
- instrument calibration and maintenance.

2.2 Monitoring of Common Quality Properties

There are several aspects of beer quality that should be monitored regularly: foam stability, flavor (in)stability, colloidal stability, microbiological stability.

Foam stability is one of the visual properties that appeal the consumer. Breweries are prone to provide a stabile and retentive foam head as it is one of the main indicators of beer freshness and quality [4]. Rich head of foam (see Fig. 1) is a property of certain types of beer (lager, pilsner, and wheat beer among others), and some do not appreciate foam in their glass, and instead they enjoy in the lacy pattern at the bottom of the finished beer [5]. Lacing or cling can be described as the adhesion of beer foam that occurs to the side of the glass during beer consumption. This is typical for Belgian beers [6]. According to [5], foam quality involves properties such as stability, retention, viscosity, whiteness, bubble size, density. Since the physics behind the foam formation and retention is so complex, many methods have been developed and are currently in use in order to quantify the quality of beer foam [7–23].

a) b)

Fig. 1. Foam stability a) and gushing b) (author's archive).

Flavor (in)stability is the major backbone of the overall perception of beer quality. Achieving the flavor stability for a longer time is a challenging process for the brewers. Due to the variety of beer styles, it is difficult to predict the exact changes in each style, but some general observations can be made based on the empirical data. For example, lagers and strong ales will display different flavor changes during storage. However, at first bitterness will decline, resulting in perceivably harsher flavor. Secondly, a decline in fruity/estery and floral notes occurs and some beers may develop a ribes (blackcurrant buds, tomcat urine) aroma. Others tend to develop a wet paper or cardboard character. Bready, sweet, toffee-like, honey, earthy, straw, hay, woody, winey and sherry-like notes can emerge as well [24–27]. Other important hurdles in delivering a good quality flavored beer are, as for foam stability, packaging, transport and storage. After packaging, the producer is rarely in control of the transporting (temperature fluctuations, agitation) and storage conditions (temperature fluctuations and time) [28]. A radical idea was proposed by Torline et al. [29] who suggested that the aged character should be maximized in beer before it leaves the brewery, on the basis that no further flavor change will occur. Flavor instability can occur in practically every step of the production, from malt to beer.

Colloidal stability is one of the important properties of beer. It refers to a non-biological haze in beer. Clarity is one of the cherished characteristics of beers such as lagers and pilsners. Beer is considered clear and brilliant if no haze forms when chilled to 4 °C or lower [30, 31]. Haziness is often considered as an error in production and as a possible health risk, so many consumers avoid hazy beers. However, some German and

Belgium wheat (white) beers are desirably hazy and the expansion of craft and organic beers on the market pushed the limits of appreciated haziness.

Fig. 2. Hazy beer (author's archive).

The lack of filtration and chemical stabilization in such beers, result in hazy beers (see Fig. 2). However, colloidal stability of beer is still the most important factor in beer quality [32] since colloidal particles significantly affect storage time, and influence its appearance as well. Nowadays, colloidal stabilization includes one or more unit operations that result in colloidal stability of beer. By definition, beer is considered to be colloidal stable if it can be stored for several months at 25 °C without exhibiting any changes in composition or other properties; in other words, beer has to be able to remain clear without any signs of precipitation. The level of colloidal stability depends on the desired storage time and temperature after packaging [32].

Ensuring the microbiological stability in beer is not as difficult as ensuring these other types of stability. As a naturally protected process (ethanol formation, low pH, antiseptic action of hop acids, low nutrient level, low oxygen concentration and carbonation), beer fermentation is not as susceptible to microbiological spoilage as one may think. There are no known human pathogens found in beer, but this should not encourage producers to omit any of the sanitation operations. There are many microorganisms that can contaminate the production so the control of microbial contaminants is an important part in ensuring consistently uniform and high quality beer [28]. This is especially important for craft breweries and homebrewers who omit the filtration and pasteurization. There are many tools available for detection, determination and quantification of microbial contaminates. To avoid or at least minimize the damage, quality control should be done in every step of the production. Recommended cleaning regimes and testing procedures should be followed. However, the best microbiological control is primarily related with [28]:

- a well-designed and maintained plant,
- application of cleaning-in-place,
- effective detergents and sterilants,
- strict microbiological monitoring.

Microorganisms should be completely absent or present in very low numbers in [28]:

- raw materials
- beer
- finished product
- strategic surfaces of process machinery (filler heads, pipes, pipelines, etc.).

Constant awareness of threats, simple hygiene and good production practice are still the most effective methods in reducing the microbiological risk.

Many associations all over the world prescribe, develop and recommend methods for beer analysis [3], and some promote brewing, especially craft entrepreneurship.

- American Society of Brewing Chemists (ASBC)
- American Homebrewers Association (AHA)
- American Malting Barley Association, Inc. (AMBA)
- Brewers Association (BA)
- Beer Institute (BI)
- Master Brewers Association of the Americas (MBAA)
- European Brewing Convention (EBC)
- Middle European Brewing Analysis Commission (MEBAK).

They all have a common interest in making the brewing quality maintenance more accessible and simple for all brewers.

The most popular in Europe are MEBAK and EBC [33, 34]. The flowing text describes some of the most important physical-chemical, microbiological, sensory and sanitation indicators of quality maintenance.

Important physical-chemical quality analysis that indicate good quality maintenance [33–36]**.**

Protein – beer proteins play an important role in foam quality and retention. They contribute to the mouthfeel, but are also responsible for haze and undesirable bitterness in beer. Methods determine the protein content of beer (% by weight) by the Kjeldahl method, by combustion, and by spectrophotometer.

Specific gravity of wort and beer – this is the ratio of the density of a substance to that of a standard substance.

Apparent extract – apparent extract is a measure of the solids dissolved in a fermenting liquid without correction for ethanol content.

Real extract – determined from the residue in the distilling flask after determination of alcohol. It corresponds to a method used for alcohol determination.

Wort and beer pH – even the slight shifts in pH values can be detected and impair the beer quality. Every beer style has its optimal pH, and this is why it should be monitored regularly.

Air injection into wort – air, or better to say oxygen form the air can act detrimental to beer causing off-flavors by oxidation. However, air is injected into wort in order to promote the yeast cell growth. Aeration is very important in the wort stage but can ruin the finished beer.

Dissolved oxygen – is usually quantified by colorimetric determination in beer where oxygen reacts with reduced indigo carmine (disodium indigo disulfonate). It is suitable for use in pale beers containing up to 2 mg/L dissolved oxygen and is recommended for calibration of dissolved oxygen analyzers.

Carbon dioxide – is a by-product of fermentation and dissolved CO_2 can be found in tanks, bottles, and cans. It is dependent on establishment by agitation of partial gas pressures in the headspace above beer in a container at a particular temperature. It is very hard to determine and quantify gaseous compounds, but these methods are sufficiently precise for the control of unit operations in breweries.

Sulfur dioxide – can be determined using the *p*-rosaniline method, Monier-Williams method, and to a limited extent, flow injection analysis, pulse polarography and ion chromatography.

Turbidity – beer clarity is an important property. Turbidity can be present due to the processing factors, as a result of aging or due to the mishandling (chilling) of the packaged product. Formazin turbidity standards have proved to provide a reference scale. This method allows the reporting of beer turbidity in formazin turbidity units.

Bitterness – the European Brewery Convention uses the EBC Bitterness Units as a uniform unit for expressing the bitter flavor of beer. There are several methods prescribed by different associations but the BU method (prescribed by ASBC) gives satisfactory similar results for bitter flavor, regardless of whether the beer was made with fresh or old hops. The IAAs (iso-α-acids) of beer brewed with old or poorly stored hops, and with certain special hop extracts, can be significantly lower than the BU figure.

Color – beer color is an essential component of the overall sensory perception of the product. Color is commonly quantified by using a spectrophotomer in order to determine the absorbance or transmittance of the sample.

Alcohol – can be determined in beer or distillate volumetrically and gravimetrically, refractometrically, by gas chromatography, low alcohol concentrations by an enzymatic method; alcohol and original extract content by using a relationship of absorbance at near-infrared wavelengths.

Viscosity – viscosity of wort and beer can indicate the content and degradation state of contributory factors, such as β-glucan, derived from malt and wort. Commonly this is enzymatic method.

Foam Quality – there are many described methods for foam stability and quality quantification, but the rate of foam collapse by the Sigma value method (modified Carlsberg method) and the foam flashing method are often used in the industry.

Important microbiological quality analysis that indicate good quality maintenance [33–35]. Here are several indicators of microbiological quality of beer.

Yeast cell counts
Yeast culture and propagation control
Yeast viability
Aerobic and anaerobic bacteria counts
Microbiological culturing media

Sensory Analysis. Beer flavor and aroma are very complex especially if we consider that it originates from raw materials used for brewing: water, barley malt, hops and yeast. Standard beer consists of about 94% water, 1–2% residual sugars, 4% ethanol and 0.1% of various flavor compounds. 0.1% seems like a minimal amount but these compounds are responsible for the unique flavor of beer. More than 1000 different flavor compounds have been identified in beer originating directly from the raw materials. Some compounds form during processing, lagering, maturation or packaging. Evolution, changes of these compounds happens during storage so the beer that has left the brewery is newer the same as the one on the consumer's table [37]. Beer aroma is related to chemical volatile compounds of the barley malt (thermal treatment during malting), hops and yeast metabolism (development of beer during fermentation and aging).However, several different volatile compounds, divided in five groups, can affect the final flavor quality of beer [38]:

- from ingredients, such as barley malt and hops,
- from roasting malt and boiling wort,
- as yeast metabolism by-products during fermentation,
- from microorganism contamination,
- from inappropriate storage conditions, such as oxygen and sunlight exposure.

The volatile compounds affect beer's organoleptic profile and are composed mainly of aliphatic and aromatic alcohols, esters, organic acids, aldehyde, carbonyl compounds, and terpenic substances. Although the raw materials are the same to majority of beer styles, some aromas and flavors are inherent for the traditionally produced beers. Many of the sensory characteristics are related to yeast metabolism during fermentation and aging. There are many reports about the (bio)chemistry of beers' sensory properties, especially regarding the composition and structure of volatile compounds. They usually vary depending on the brewing process, yeast strain, raw-material (wheat vs. barley malt), etc. [39–50].

Sanitation [51]. Often the most important quality management can be done by simple proper sanitation in the brewing industry. Stainless steel (grade 304 or 316) [52] is the best material for brewing equipment, it is easy to clean, highly resistant to corrosion, and it is relatively ductile. Special attention should be payed for cleaning the welded conjunctions due to possible bacteria build up in them. Cleaning can be performed in different ways:

- sterilization - destroys any form of life
- disinfection - kill the microorganisms that are of concern
- sanitization - lowering the number of contaminants to the acceptable level
- cleaning - removing the visible and larger scale dirt [53].

High temperatures and the addition of hops (antibacterial agent) during brewing process inhibit the possible bacterial contamination. Low pH values, low oxygen and nutrients on one hand and concentration of ethanol on the other act preventative to contaminants. Cleaning in Place (CIP) is a common practice for the industry. COP (Cleaning Out of Place), is sometimes used too due to the easier visual inspection. However, it does take up a lot more time. Proper cleaning requires the following steps:

- wetting of the equipment
- reaction between the soil and the water/chemical used
- removal of both
- prevention of reoccurrence [51].

Disinfection can prevent microbial regrowth and some disinfectants used in industry include peracetic acid, hydrogen peroxide, and chlorine [53]. An important issues that should be addressed is the use of environmentally and economically friendly cleaning agents.

3 Conclusions

Maintaining a good quality product is very hard, especially with a medium such as beer. The fluctuations in raw material quality and process parameters make it hard to deliver a standardized and uniform beer to the consumer. Packaging, transport and storage make this job even harder since many variables such as temperature fluctuations, oxygen and storage time significantly influence the beer quality. Therefore, continuous and dedicated quality control by applying the required manufacturing and laboratory practice, should result in quality beer on the tables of the consumers. Breweries should implement a good quality policy, including procedures for managing the quality of its brands and raw materials, packaging materials and final products. The best way to implement quality is to acknowledge some of the QMS (Quality Management System) or FSMS (Food Safety Management System). The implementation of ISO 9001 standard and the HACCP standard should result in quality improvement. Outsourcing of food safety and quality experts, and regular monitoring of customers satisfaction are key factors in insuring the quality maintenance during beer production process.

References

1. Brewing Quality Control and Quality Management. https://www.brewer-world.com/brewing-quality-control-and-quality-management/. Accessed 19 Aug 2021
2. Vrellas, C.G., Tsiotras, G.D.: Quality management in the global brewing industry. Int. J. Qual. Reliab. Manag. **32**(1), 42–52 (2015)
3. Amad, M.J.: Aspects of Brewing Quality Control. https://cdn.ymaws.com/www.acil.org/resource/resmgr/annual_meeting/2016_am/Aspects_of_Brewing_Quality_C.pdf. Accessed 19 Aug 2021
4. Nyarko, E.K., Glavaš, H., Habschied, K., Mastanjević, K.: Determination of foam stability in lager beers using digital image analysis of images obtained using RGB and 3D cameras. Fermentation **7**(2), 46 (2021)
5. Bamforth, C.W.: The foaming properties of beer. J. Inst. Brew. **91**, 370–383 (1985)
6. BJCP, Beer Style Guidelines. Edited by Gordon Strong, Kristen England. www.bjcp.org. Accessed 24 Aug 2021
7. Hackbarth, J.J.: Multivariate analyses of beer foam stand. J. Inst. Brew. **112**, 17–24 (2006)
8. Prins, A., van Marle, J.T.: Foam formation in beer: some physics behind it. In: Monographs of the European Brewing Convention, vol. 27, pp. 26–36 (1999)
9. Ronteltap, A., Hollemans, M., Bisperink, C.G.J., Prims, A.R.: Beer foam physics. Tech. Q. Master Brew. Assoc. **28**, 25–32 (1991)
10. Fisher, S., Hauser, G., Sommer, K.: Influence of dissolved gases on foam. In: Monographs of the European Brewing Convention, vol. 27, pp. 37–46 (1999)
11. Evans, D.E., Sheehan, M.C.: Don't be fobbed off: the substance of beer foam—a review. J. Am. Soc. Brew. Chem. **60**(2), 47–57 (2002)
12. ASBC. Methods of Analysis. Method Beer-22. Foam Collapse Rate. Approved 1962, rev. 1975; American Society of Brewing Chemists: St. Paul, MN, USA (2018)
13. Klopper, W.: Foam stability and foam cling. In Proceedings of the Congress on European Brewery Convention. Elsevier, Amsterdam, The Netherlands (1964)
14. Rudin, A.: Measurement of the foam stability of beers. J. Inst. Brew. **63**, 506–509 (1957)
15. Rasmussen, J.N.: Automated analysis of foam stability. Carlsberg Res. Commun. **46**(1–2), 25–36 (1981). https://doi.org/10.1007/BF02906195
16. Jackson, G., Bamforth, C.: The measurement of foam-lacing. J. Inst. Brew. **88**, 378–381 (1982)
17. Constant, M.: A practical method for characterizing poured beer foam quality. J. Am. Soc. Brew. Chem. **50**, 37–47 (1992)
18. Vundla, W., Torline, P.: Steps toward the formulation of a model foam standard. J. Am. Soc. Brew. Chem. **65**, 21–25 (2007)
19. Amerine, M.A., Martini, L., Mattei, W.D.: Foaming properties of wine. Ind. Eng. Chem. **34**, 152–157 (1942)
20. Wilson, P., Mundy, A.: An improved method for measuring beer foam collapse. J. Inst. Brew. **90**, 385–388 (1984)
21. Evans, D.E., Surrel, A., Sheehy, M., Stewart, D.C., Robinson, L.H.: Comparison of foam quality and the influence of hop α-acids and proteins using five foam analysis methods. J. Am. Soc. Brew. Chem. **66**, 1–10 (2008)
22. Evans, D.E., Oberdieck, M., Red, K.S., Newman, R.: Comparison of the Rudin and NIBEM methods for measuring foam stability with a manual pour method to identify beer characteristics that deliver consumers stable beer foam. J. Am. Soc. Brew. Chem. **70**, 70–78 (2012)
23. Smith, R.J., Davidson, D., Wilson, R.J.: Natural foam stabilizing and bittering compounds derived from hops. J. Am. Soc. Brew. Chem. **56**, 52–57 (1998)

24. Drost, B.W., Eerde, P., Van Hoekstra, S., Strating, J.: Fatty acids and the staling of beer. In: Proceedings of the 13th European Brewery Convention Congress, Estoril, vol. 9, pp. 451–458 (1971)
25. Meilgaard, M.: Stale flavor carbonyls in brewing. Brew. Dig. **47**, 48–57 (1972)
26. Whitear, A.L.: Factors affecting beer stability. In: EBC Flavor Symposium, Monograph VII, pp. 203–210 (1981)
27. Dalgliesh, C.E.: Flavour stability. In: Proceedings of the 16th European Brewery Convention Congress, Amsterdam, pp. 623–659 (1977)
28. Bamforth, C.W.: Beer: A Quality Perspective, 1st edn. Academic Press Elsevier, New York (2009)
29. Torline, P., Dercksen, A., Axcell, B.: An electronic look at beer flavor instability. Master Brew. Assoc. Am. Tech. Q. **36**, 289–292 (1999)
30. Briggs, D.E., Boulton, C.A., Brookes, P.A., Stevens, R.: Brewing: Science and Practice. Woodhead Publishing Limited, Cambridge (2004)
31. Lewis, M.J., Young, T.W.: Brewing, 2nd edn. Kluwer Academic and Plenum Publishers, New York (2002)
32. Mastanjević, K., Krstanović, V., Lukinac, J., Jukić, M., Vulin, Z., Mastanjević, K.: Beer-the importance of colloidal stability (non-biological haze). Fermentation **4**(4), 91 (2018)
33. Middle European Brewing Analysis Commission (MEBAK), 3rd edn. Selbstverlag der MEBAK, Freising-Weihenstephan, Germany (1997)
34. European Brewery Convention (EBC), Analytica, 5th edn. Fachverlag Hans Carl, D-Nürnberg, Germany (1998)
35. ASBC methods. https://www.asbcnet.org/Methods/BeerMethods/Pages/default.aspx. Accessed 21 Aug 2021
36. Guido, L.F.: Sulfites in beer: reviewing regulation, analysis and role. Scientia Agricola **73**(2), 189–197 (2016)
37. Parker, D. K.: Beer: production, sensory characteristics and sensory analysis. In: Alcoholic Beverages, pp. 133–158 (2012)
38. Humia, B.V., Santos, K.S., Barbosa, A.M., Sawata, M., Mendonça, M.D.C., Padilha, F.F.: Beer molecules and its sensory and biological properties: a review. Molecules **24**(8), 1568 (2019)
39. Holt, S., Mukherjee, V., Lievens, B., Verstrepen, K.J., Thevelein, J.M.: Bioflavoring by non-conventional yeasts in sequential beer fermentations. Food Microbiol. **72**, 55–66 (2018)
40. Mastanjevic, K., et al.: From malt to wheat beer: a comprehensive multi-toxin screening, transfer assessment and its influence on basic fermentation parameters. Food Chem. **254**, 115–121 (2018)
41. Kobayashi, M., Shimizu, H., Shioya, S.: Beer volatile compounds and their application to low-malt beer fermentation. J. Biosci. Bioeng. **106**, 317–323 (2008)
42. Dack, R.E., Black, G.W., Koutsidis, G., Usher, S.J.: The effect of Maillard reaction products and yeast strain on the synthesis of key higher alcohols and esters in beer fermentations. Food Chem. **232**, 595–601 (2017)
43. Rodman, A.D., Gerogiorgis, D.I.: Dynamic optimization of beer fermentation: Sensitivity analysis of attainable performance vs. product flavor constraints. Comput. Chem. Eng. **106**, 582–595 (2017)
44. Stefanuto, P.H., et al.: Advanced method optimization for volatile aroma profiling of beer using two-dimensional gas chromatography time-of-flight mass spectrometry. J. Chromatogr. A **1507**, 45–52 (2017)
45. Toh, D.W.K., Chua, J.Y., Liu, S.Q.: Impact of simultaneous fermentation with *Saccharomyces cerevisiae* and *Torulaspora delbrueckii* on volatile and non-volatile constituents in beer. LWT Food Sci. Technol. **91**, 26–33 (2018)

46. Ocvirk, M., Mlinaric, N.K., Kosir, I.J.: Comparison of sensory and chemical evaluation of lager beer aroma by gas chromatography and gas chromatography/mass spectrometry. J. Sci. Food Agr. **80**, 3627–3635 (2018)
47. Quifer-Rada, P., et al.: A comprehensive characterisation of beer polyphenols by high resolution mass spectrometry (LC–ESI-LTQ-Orbitrap-MS). Food Chem. **169**, 336–343 (2015)
48. Da Silva, G.C., et al.: Method development by GC–ECD and HS-SPME–GC–MS for beer volatile analysis. Food Chem. **167**, 71–77 (2015)
49. Bogdan, P., Kordialik-Bogacka, E.: Alternatives to malt in brewing. Trends Food Sci. Technol. **65**, 1–9 (2017)
50. Gagula, G., Mastanjević, K., Mastanjević, K., Krstanović, V., Horvat D., Magdić, D.: The influence of packaging material on volatile compounds of pale lager beer. Food Packag. Shelf Life **24**, 100496 (2020)
51. Deraney, N., Manning, J., Morse, L., Palmer, J.: Efficient Brewery Sanitation. https://web.wpi.edu/Pubs/E-project/Available/E-project-042215-141239/unrestricted/Efficient_Brewery_Sanitation_MQP__Deraney_Manning_Morse_Palmer.pdf. Accessed 21 July 2021
52. The Alloys of Brew. https://www.reliance-foundry.com/blog/brewing-metallurgy. Accessed 21 Sept 2021
53. Cluett, J., Rowlands, D., Khanyile, D., Hulse, G.: Principles of Hygiene in the Beverage Industry, 1st edn. The Institute of Brewing and Distilling (IBD)–Africa Section, Supreme Printers, Hout Bay, South Africa (2003)