Italian Journal of Food Science, 2024; 36 (3): 20–39

Innovative trends and strategies for the integral valorization of products in the beer supply chain

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Received: 16 February 2024; Accepted: 7 May 2024; Published: 1 July 2024

REVIEW ARTICLE

Abstract

This review aims to explore the latest innovations in beer supply chain. Innovation is defined as the combined application of strategies that enhance intrinsic and extrinsic product characteristics while optimizing complementary aspects for a modern approach to the food market. The study is structured around key themes that define the overall quality of beer supply chain: safety (wholesomeness and authenticity), biological quality (chemical composition, sensory profile, and nutritional quality), process quality, convenience, and commodities. The goal is to promote accurate dissemination of information within the beer community and dispel common misconceptions. These misconceptions often arise from flawed approaches, leading to the creation of urban legends and unfounded prejudices. Special attention is given to innovation and research in the craft beer sector, which is rapidly growing in Italy and the global market.

Keywords: authenticity; brewing sector; chemical composition; convenience and commodities; nutritional quality; overall quality; processing; sensory profile; wholesomeness

Introduction

Beer is the most predominant and economically significant fermented alcoholic beverage worldwide, surpassing both wine and spirits, because of its long tradition (Oxford Economics, 2022).

The history of beer dates back to the Assyrians and Babylonians, who inhabited Mesopotamia 4000 years BC, where ancient grains (now cultivated) were fermented according to specific rules as outlined in the Code of Hammurabi, the sixth king of the first Babylonian empire. This code mandated that every citizen be provided with a daily ration of beer, distributed based on social status: 2 L, 3 L, and 5 L per day for workers or civil servants, administrators, and high priests, respectively (jstrack.org – A History of Beer).

Beer is a widely consumed beverage, made from malt (germinated barley), hops (*Humulus lupulus* L.), water, and yeast, and it is one of the main pillars of the Italian agrifood system (Fantozzi, 2017; Sohrabvandi *et al.*, 2012). The recent increase in craft and experimental beer production has resulted in the recognition of various traditional beer types. In addition, the growing consumer demand for a wider range of beer options, including sweeter ones, has promoted the emergence of new types of beers (Croonenberghs *et al.*, 2024). According to the 2022 Unionbirrai report 'craft beer, supply chain and markets', which was officially presented in June 2023, the current state of the brewing sector in Italy is very positive.

The Italian craft beer industry is experiencing a boom, given that this sector has grown in recent years in terms

 ISSN 1120-1770 online, DOI 10.15586/ijfs.v36i3.2542

of quality and production. At the end of December 2022, 1,326 craft breweries were operating in Italy (with an increase of 104% in the last 7 years, compared to 2015), with a total beer production of around 17.6-million hectoliters (hL). Currently, Italy ranks sixth in Europe in terms of the number of craft breweries, behind France, United Kingdom, Germany, Switzerland, and the Netherlands. The craft beer market covers just over 3% of the national market, although Italy imports almost all the raw materials required for beer production, especially hops (Gargani *et al.*, 2017; Unionbirrai, 2023). Recent data show a steady increase in companies dedicated to hop cultivation. In 2020, there were 165 agricultural companies cultivating hop plants at a national level, covering a total area of 67 ha. More than 80% of these companies followed a certified organic regime (Unionbirrai, 2023).

According to the Italian Law n. 1354/1962 (Legge 16 agosto, 1962 n. 1354), beer is 'the product obtained from the alcoholic fermentation with strains of *Saccharomyces carlsbergensis* or *S. cerevisiae* of wort prepared with malt, whether [roasted] or not roasted, of barley or wheat, or mixtures thereof and water, flavored with hops or its derivatives or with both'. However, this law does not provide a specific definition of 'craft beer', but it refers to a 'craft brewery' (article 2, comma 4-bis) when it mentions a 'small independent brewery', whose annual production does not exceed 200,000 hL.

The 'craft beer', as developed through various studies conducted by industry experts, is defined as the beer produced by small independent breweries and not subjected to pasteurization or microfiltration processes during the production phase to be considered 'small independent breweries', the breweries must be legally and economically independent from any other brewery. They must use their own production plants and should not exceed an annual production of 200,000 hL of beer (as specified legally). The label of the produced beer must have the indication of 'birra artigianale'. The ministerial decree n. 212 (Decreto Legislativo 13 dicembre, 2010) recognized beer as an 'agricultural product', and the 'agricultural brewery' was recognized as a company that includes the production of malt and beer among its activities, qualifying it for income tax purposes.

With the following ministerial decree (Decreto del 4 giugno, 2019), Italian law refers to 'microbrewery' as independent breweries with an annual production not exceeding 10,000 hL.

Since some other specific regulatory aspects remain unresolved, the beer sector, including both industrial and craft breweries, is able to approach the innovation from various and often original perspectives. Specifically, in the food sector, innovation involves the introduction of untested strategies for products and/or processes, or significant improvements in the efficiency of the existing production chains. Innovation refers to procedures, standards, rules, activities, or the introduction of new ingredients, methods, formulations, or tools to achieve a specific result.

The brewing industry's commercial significance highlights the strategic importance of scientific dissemination in providing a comprehensive and up-to-date overview of the research conducted in this field. It also serves as a reference point for professionals and enthusiasts. Despite being a traditional drink, beer has undergone innovations in the overall quality within the context of current legislation (Cabras and Higgings, 2016; jstrack.org – A History of Beer). Innovation refers to strategies aimed at improving the intrinsic characteristics of a product and optimizing ancillary aspects, such as convenience and commodities (Raihofer *et al.*, 2022).

With these premises, this review focuses on the aspects related to the wholesomeness and authenticity of beer, emphasizing the importance of adequately controlled production that enhances raw materials and processes, both traditional and industrial. In fact, beer is considered a healthy and genuine beverage if made with high-quality ingredients and produced according to rigorous standards. This requires particular attention to beer's chemical–physical quality, including the parameters that determine its sensory characteristics and shelf life. The study also covers emerging trends in the beer market, such as gluten-free and non-alcoholic beer, with a focus on growing interests in aspects such as convenience and commodities. Scientific dissemination plays a key role in promoting a conscious and informed beer culture. This review emphasizes the importance of communicating scientific knowledge about beer to public, promoting a better understanding of its nutritional, health, and production aspects.

This study represents a contribution to the growth of the brewing sector by providing a solid and updated knowledge base to all stakeholders, such as researchers, producers, distributors, and consumers. Its emphasis on wholesomeness, authenticity, preconditions for overall quality, and scientific dissemination adds value to both entire production chain and beer culture in general.

Food safety and health aspects and analytical control

Beer is the most consumed alcoholic beverages globally, with nutritional and medicinal benefits for consumers (Tirado-Kulieva *et al.*, 2023). From a nutritional perspective, beer contains protein, vitamin B, and some minerals.

Compared to wine, protein and vitamin B levels in beer are higher. Although beer and wine have similar antioxidant content, specific antioxidants differ in the both. From a medical perspective, certain components, such as phenolic compounds, ethanol, and dietary fibers, are also important (Sohrabvandi *et al.*, 2012). Beer also contains melatonin (N-acetyl-5-methoxytryptamine), a molecule with a wide range of antioxidant, oncostatic, immunomodulatory, and cytoprotective properties (Maldonado *et al.*, 2022). Based on this composition, the following properties of beer are discussed here.

Beer consumption and its effects on homeostasis and cardiovascular diseases

It has been widely demonstrated that moderate consumption of beer with its non-alcoholic components has a beneficial effect on the cardiovascular system, especially when combined with pharmacological or integrative therapy. Furthermore, several studies have demonstrated the influence of beer components on homeostasis (Sohrabvandi *et al.*, 2012; Tirado-Kulieva *et al.*, 2023). Although dietary guidelines generally recommend a maximum daily consumption of 25–40 cL for women and twice this amount for men, these parameters can vary depending on the factors such as age, body type, physical activity, etc. (Cabras and Higgings, 2016; Callemien *et al.*, 2005).

As a result, recommendations for moderate beer consumption are often based on individual cases and small clinical trials. The nutritional and medicinal benefits of beer are attributed to several components, such as phenolic compounds (with multifunctional properties, such as antiplatelet drugs and antioxidant compounds) and relatively low concentrations of ethanol. The drawbacks are primarily due to a higher likelihood of consuming stronger alcoholic beverages than wine and, to a lesser extent, ingesting allergens (Chiva-Blanch *et al.*, 2015). However, it is challenging to establish a clear correlation between specific components of beer and their beneficial effect for preventing cardiovascular diseases and treatment as well as for the overall homeostasis of organism (De Gaetano *et al.*, 2016).

Beer antioxidants and health benefits

The presence and amount of nutrients and bioactive compounds in beer depends on ingredients, including malted grains and cereals (barley, wheat, oats, and rice), hops, adjuncts, such as fruits and spices, and microorganisms, such as *Saccharomyces* yeasts or co-fermentation bacteria of the genus *Lactobacillus* (De Simone *et al.*, 2021). Various types and styles of beer contain specific molecules with antioxidants (Krofta *et al.*, 2008) and anti-inflammatory properties (Di Domenico *et al.*, 2020). Hops and malt are raw materials used in beer production and are sources of phenolic compounds, which are among the main health-related compounds present (Salanță *et al.*, 2020). In fact, about 30% of the polyphenols in beer come from hops and 70–80% from malt (Taylor *et al.*, 2003).

The main antioxidant compounds in beer are phenolic compounds and melanoidin, which are formed through the Maillard reaction (Maldonado *et al.*, 2022). Additionally, some antioxidant additives used in beer (i.e., ascorbic acid) may also contribute to the beer's antioxidant capacity. Furthermore, hops contain a resin that includes monoacyl phloroglucinols, which become bitter acids during the beer development process, such as α-acids (humulones) and iso-α-acids. The structural classes of polyphenols in beer include simple phenols, benzoic acid derivatives, and cinnamic acid, coumarins, catechins, di- and trioligomeric pro-anthocyanidins, prenylated chalcones, α-acids, and iso-α-acids derived from hops (Arranz *et al.*, 2012).

Total polyphenols and phenolic acid contents vary greatly among different types of beer, depending on the variety of hops used and the production method. However, it is very rare for consumers to find information on the specific variety of hops used, making it difficult to identify a beer by its polyphenol content. Ferulic acid is the most abundant phenolic acid in various commercial beer types, such as abbey, ale, bock, wheat, lager, pilsner, and dealcoholized. It is followed by synaptic, vanillic, caffeic, p-coumaric, and 4-hydroxyphenylacetic acids. Ferulic, caffeic, syringic, synaptic, and vanillic acids are present in beers mainly in bound forms, while p-coumaric and 4-hydroxyphenylacetic acids are generally present equally in both free and bound forms (Humia *et al.*, 2019; Piazzon *et al.*, 2010; Tatullo *et al.*, 2016).

Phenolic compounds contribute positively to beer in several ways, such as stability. Certain phenolics act as antioxidants, protecting beer from spoilage caused by oxidation (Carvalho and Guido, 2021). Additionally, some studies suggest that moderate consumption of beer with high levels of certain phenolic compounds, such as ferulic acid, may have some health benefits (Ambra *et al.*, 2021).

Xanthohumol and its derivatives are the most potent antioxidant compounds found in hops, followed by isoxanthohumol and other prenylflavonoids, such as 6-prenylnaringenin (6-PN) and 8-prenylnaringenin (8-PN), which are obtained from hops (Osorio-Paz *et al.*, 2020). Xanthohumol is known for its broadspectrum biological activity. It also possesses antibacterial, antiviral, and antifungal properties (Niknejad *et al.*, 2014; Zugravu *et al.*, 2022), which have also been demonstrated *in vitro* (Yamaguchi *et al.*, 2009). Recent studies have suggested that xanthohumol is potentially an antitumor agent, particularly in diseases such as glioblastoma (Luo *et al.*, 2024).

Having a high content of antioxidants does not necessarily imply that beer consumers are abusing alcohol, as taught by the 'French paradox' of resveratrol (RSV) in wines. Moderate alcohol consumption has been associated with a lower risk of developing cardiovascular diseases, compared to both nondrinkers and heavy drinkers (De Gaetano *et al.*, 2016; Mellor *et al.*, 2020). The risk increases exponentially with the increasing doses of alcohol consumed. Moderate beer consumption can benefit our vascular system by reducing the oxidation of low-density lipoprotein (LDL), which is one of the five major groups of lipoproteins that transport fat molecules around the body in extracellular water. Additionally, it can help to maintain the integrity and functionality of blood vessels oxidation and in reducing inflammatory phenomena in cerebral vascular tissues (Krofta *et al.*, 2008).

Antioxidants modulate the production of substances that regulate blood pressure and glucose levels (De Gaetano *et al.*, 2016; Krofta *et al.*, 2008), blood coagulation, and reduce atherogenesis (Coulibaly *et al.*, 2023; De Gaetano *et al.*, 2016) as well as modulate inflammatory processes (Gerhäuser, 2005; Rancán *et al.*, 2017; Romeo *et al.*, 2007). Moderate alcohol consumption has been shown to have a neuroprotective effect by reducing the levels of amyloid beta, a protein involved in neurodegenerative diseases, such as Alzheimer's disease and Parkinsonism (Mellor *et al.*, 2020; Rancán *et al.*, 2017).

Beer contains melatonin, derived from cereals and yeast (*S. cerevisiae*) used in its production, particularly during second fermentation. The amount of melatonin in beer varies depending on the fermentation conditions, the quality of the cereals used, alcohol strength of beer, and the processing system used. Melatonin is a multifaceted substance that acts as a free radical scavenger, antioxidant, and anti-inflammatory agent. It has also a preventive effect against oxidative stress, and has an immunomodulatory effect on the immune system. It has also demonstrated anticancer properties *in vitro* and *in vivo*, acting through various mechanisms and in various tumors. Additionally, it has been found effective on bone mass and as a neuroprotective agent. Interestingly, craft beers have higher levels of melatonin than commercial ones with equal level of alcohol (Maldonado *et al.*, 2022).

Excessive consumption of alcoholic beverages leads to health disorders, such as allergy, increased plasma concentration of uric acid, mutations and cancer, increased risk of dementia, obesity, and social misbehavior (Collins *et al.*, 2009; Sohrabvandi *et al.* 2012). On the contrary, light to moderate consumption of alcoholic beverages, including beer with relatively low alcohol content, can have various favorable effects on human health. These include nutritional benefits, antimutagenic and anticarcinogenic effects, reduction of cardiovascular diseases (cardioprotective effect), hypolipidemic effect, stimulation of immune system, anti-osteoporosis effect, and reduced risk of dementia (Sohrabvandi *et al.* 2012; Tirado-Kulieva *et al.*, 2023).

The results of different scientific studies (Collins *et al.*, 2009; Gerhäuser, 2005; Krofta *et al.*, 2008; Rancán *et al.*, 2017; Romeo *et al.*, 2007; Tirado-Kulieva *et al.*, 2023) suggest that a moderate daily alcohol consumption (i.e., 24 g per day, or about 500 mL of beer) may reduce the risk of developing type 2 alimentary diabetes. This could be due to the stimulation of adiponectin, a protein synthesized by adipose tissue. Adiponectin improves the sensitivity of the liver and muscle cells to glucose, thereby enhancing insulin sensitivity (Ministero della Salute, Nutrizione, 2023; Nutrisense, 2023). This may be contradictory to the fact that beer has a high glycemic index (around 110) and therefore is not recommended in the diet of people with diabetes mellitus or glucose intolerance. The evidence of *in vivo* total antioxidant capacity after consumption of beer is still limited and inconclusive. It is important to note that generalizations cannot be made due to varying residual sugar content in different types of beer. The range of residual sugar in different beer varieties is wide, with the driest varieties, such as lambic, some saisons, and other Belgian specialties, having less than 1% residual sugar by weight. On the other hand, some heavy barley varieties have a syrupy 10% residual sugar (Craft Beer & Brewing, 2006; The Italian Craft Beer, 2019).

Beer does not raise blood sugar levels but it tends to lower the glycemic peak when consumed with or before a carbohydrate-rich meal. It is possible that alcohol can reduce the production of glucose in the liver, which may help compensate for the glucose ingested with meals. However, diabetics can drink beer and have some health benefits because of its ability to control blood sugar and reduce cardiovascular risks associated with diabetes (Nutrisense, 2023).

Meta-analysis has identified an inverse association between total alcohol consumption and the risk of type 2 diabetes. Huang *et al.* (2017) conducted a study to explore the relationship between specific types of alcoholic beverages and the incidence of type 2 diabetes. The meta-analysis included 13 prospective studies, with 397,296 study participants and 20,641 cases of type 2 diabetes. Compared to any or rare alcohol consumption, wine consumption was significantly associated with reducing the risk of type 2 diabetes (pooled relative risk of 0.85), while consumption of beer and spirits showed a slight trend toward decreased risk of type 2 diabetes with relative risk of 0.96 and 0.95, respectively. Further dose–response analysis revealed a U-shaped relationship between all three alcohol types and type 2 diabetes. The meta-analysis revealed that the peak risk reduction occurred at 20–30 g/day for wine (20% decrease) and beer (9% decrease), and at 7–15 g/day for spirits (5% decrease). The evidence strongly suggested that specific alcoholic beverages had different effects on reducing the risk of type 2 diabetes. Specifically, wine consumption was associated with a significant reduction in the risk of type 2 diabetes, while consumption of beer and spirits showed a slight decrease in the risk of type 2 diabetes (Huang *et al.*, 2017).

In addition, alcohol has a direct effect on the renal system and is a significant diuretic (within 20 min of ingestion) because of the inhibition of hormone vasopressin, which promotes the reabsorption of water excreted in urine. Although this may seem as a positive effect, in chronic consumers, it could lead to the subsequent malfunctioning of the kidneys and dysregulation of body fluids and minerals necessary to carry out important basic functions of an organism (Collins *et al.*, 2009; Krofta *et al.*, 2008; Raihofer *et al.*, 2022; Rancán *et al.*, 2017; Romeo *et al.*, 2007).

Even the immune system seems to benefit from a moderate consumption of alcoholic beverages rich in polyphenols. The number of cells and molecules involved in immune response and their ability to fight foreign agents has increased, but it is essential to check quantities because excessive consumption, especially if chronic, has immunosuppressive effects (Romeo *et al.*, 2007).

The consumption of beer after sports activity is considered favorable for its remarkable content of minerals and vitamins, utility to rebalancing water and salt, and antioxidant and anti-inflammatory properties. Therefore, drinking beer after exercise could be counterproductive due to the diuretic effect of alcohol. Alcohol is not considered a nutrient because, although it provides energy (7 kcal/g), it has no specific functional and/or metabolic purpose (Metro *et al.*, 2022).

Alcohol is also defined as a potential social danger that can lead to physical and psychological damage, an increased risk of cardio-cerebrovascular diseases, liver and gastrointestinal diseases as well as some forms of cancer (Kummetat *et al.*, 2022). However, there is another activity of phenolic compounds, that is, to counteract the negative effects of acetaldehyde produced by the metabolism of alcohol and classified as a possible human carcinogen (group 2B) by the International Agency for Research on Cancer (AIRC) (Lachenmeier and Sohnius, 2008; Seitz and Stickel, 2010). In particular, polyphenols prevent inflammatory phenomena, the proliferation of cancer cells, and the formation of new blood vessels that carry nourishment to cancer cells (Gerhäuser, 2005; Romeo *et al.*, 2007).

Santarelli *et al.* (2022) proposed a new green and rapid method to extract phytochemicals from hops for their use as food additives, such as high hydrostatic pressure (HHP) and ultrasound-assisted extraction (UAE). Both methods had better effects on bioactive compounds, with particular attention to ultrasound extraction because of short time and low energy requirement.

Promotion of redox state and positive effects on the liver *in vivo*

Moderate consumption of beer may have beneficial effects against chronic diseases because of the presence of flavonoids in hops. The total antioxidant potential of eight beers belonging to five different styles was studied (Mori *et al.*, 2016). Craft beers had higher antioxidant properties than standard American lagers, while imperial red ale showed the highest antioxidant properties *in vitro*.

Gasowski *et al.* (2004) investigated the effect of moderate consumption of beer on redox parameters and liver integrity in Wistar rats exposed to carbon tetrachloride (CCl_4). The *in vivo* redox effects of beers were observed in 70 male Wistar rats through liver histologic evaluation of hepatoprotective effect against CCl_4-induced liver injury, including silymarin. In addition, *in vivo*, American lager and red imperial beers induced changes in the homeostasis of the biosystem by modulating the activity of antioxidant enzymes. After the addition of CCl_4, Imperial Red ale increased the enzymatic activity of superoxide dismutase (SOD) and catalase (CAT), with effects similar to those of silymarin. Imperial Red ale produced the best results, showing a silymarin-like effect on abdominal fat and serum and liver redox status, suggesting that moderate consumption of this beer is not harmful and may increase enzyme redox status and not after the addition of CCl_4. In conclusion, craft beers appear to enhance enzyme and antioxidant activity and are healthier than standard American lager (Caon *et al.*, 2021; Kuwabara *et al.*, 2008).

Gluten-free and non-alcoholic beers

Market demand has forced breweries to adapt to celiac consumers, people suffering from diagnosed celiac disease or mild forms of gluten intolerance, although in 2021 they represented only 1% of the Italian population (Ministero della Salute, Nutrizione, 2023). Several studies were published in this field, most of them were carried out by Italian authors committed to developing a gluten-free product but at the same time tastes like beer obtained from malted barley. Table 1 shows some proposals for gluten-free beers. Some authors proposed the use of legume grains, sorghum, teff, and rice, although the substitution of barley sometimes resulted in a less flavored and paler beer and lower foam stability (Rancán *et al.*, 2017).

Several gluten-free beers are produced with a fair success in the Italian market. The 'Cantine di Birra' website (Cantine della Birra, 2023; The Italian Craft Beer, 2019) lists around 50 gluten-free Italian beers, with the following being the most popular ones: Birrificio Baladin (Nazionale gluten free, Nora, Isaac, Xyauyu), Birrificio Menabrea (Menabrea gluten free); Birrificio Peroni (Peroni gluten free); Birrificio Poretti (4 Luppoli gluten free); Birrificio La Superba (Superba gluten free); Birrificio del Ducato (Ducato gluten free); Birrificio Maltus Faber (Bière du Maltus faber); Birrificio Hammer (Hammer gluten free); Birrificio Hibu (Hibu gluten free); Birrificio La Birra Moretti (La Birra Moretti Zero Glutine); Birrificio Ichnusa (Ichnusa gluten free); Birrificio Messina (Messina Cristalli di Sale gluten free); Birrificio Peroni (Peroni gluten free); Birrificio Forst (Forst gluten free); Birrificio San Pellegrino (San Pellegrino gluten free); Birrificio Dreher (Dreher gluten free); Birrificio Wührer (Wührer gluten free); Birrificio Antoniana (Antoniana gluten free); Birrificio Flea (Flea gluten free); Birrificio La Goccia (La Goccia gluten free); Birrificio artigianale Birra Moretti (Birra Moretti zero Glutine); and Birrificio artigianale Ichnusa (Ichnusa gluten free).

Another technological innovation that has affected the expansion of beer market is represented by non-alcoholic varieties. Non-alcoholic beer is a great option for people who are looking for a healthy and refreshing beverage. It is also a good choice for people who are abstaining from alcohol or pregnant or breastfeeding females (Salanță *et al.*, 2020; Sileoni *et al.*, 2023).

Non-alcoholic beer is made by removing alcohol from regular beer varieties through evaporation, distillation, or filtration. According to a recent report brought out by Grand View Research (2022) and Hops Farmer Il notiziario sulla filiera del Luppolo in Italia (2020), the non-alcoholic beer market is projected to grow at a compound annual growth rate (CAGR) of 8.9% from 2022 to 2030. This growth is driven by various factors, such as increasing popularity of healthy and non-alcoholic beverages, growing demand for convenient and ready-to-drink beverages, and rising disposable incomes of consumers in developing countries. Non-alcoholic beer is now available in a wide variety of styles, including lagers, ales, stouts, and India pale *ales (*IPAs). A number of large breweries and craft breweries are specializing in non-alcoholic beer. Popular non-alcoholic beer options include Heineken 0.0, Budweiser Zero, Athletic Brewing Run Wild IPA, Lagunitas IPNA, and Erdinger Alkoholfrei.

Table 1. Gluten-free beer types in literature.

Matrix added	Fermentative method	Sensory appearance	Country	References
Legume grains and Italian legumes			Umbria and Italy	Ferreira *et al.*, 2021; Luneia *et al.*, 2018
Mixture of peas, beans, and oats				Markham, 1986; Saget *et al.*, 2022
Malted lentils, fava beans flour, no malted chicking, and lentils grains			Poland, Belgium, and United Kingdom	Black *et al.*, 2019; Luneia *et al.*, 2018; Trummer *et al.*, 2021
Sorghum malts, teff malts, oats, and malts	Bottom-fermented		Italy, Slovenia, and Germany	Cela *et al.*, 2023; Zhao *et al.*, 2023
Rice malt (100%) and brown rice		Flat sensory profile and pale color	China and Italy	Ceccaroni *et al.*, 2019; Zhao *et al.*, 2023
Special rice malts, caramel malt, and dark rice malt	Top-fermented	Malty flavor, amber color, stability, and nutritional profile	Italy	Ceccaroni *et al.*, 2018, 2019
Germinated brown rice (*Oryza sativa* L.)			China	Zhao *et al.*, 2023
Raw and malted teff	Top-fermented	Sweet fruity sensory profile with little body (raw teff); dried fruit, biscuit, and vanilla (malted teff)	Italy	Di Ghionno *et al.*, 2017
Prolyl endopeptidase from *Aspergillus niger* and precipitation with silica gel	American Indian pale ale			Fanari *et al.*, 2018

European Brewers Convention (EBC) analytical methods assessment

The EBC (Knowledge Center Brew Up by the Brewers of Europe, 2019) has developed reference methods for the control of beer and/or raw material parameters. All methods listed in Table 2 provide fast and easy results.

Color and low turbidity are the most important aspects of a consumer choice of beer. Therefore, the use of image analysis is important and objective. The image acquisition and data analysis characterize the appearance of food and its evolution as a result of operational, physiological, or environmental factors, acquiring images with various devices, such as cameras (traditional or smartphone), scanners, and microscopes, subsequently stored in computers and analyzed by using appropriate programs and algorithms that allow the image to be segmented into significant elements and to automatically extract color or geometry measurements (de Oliveira Krambeck Franco *et al.*, 2021). The software allows selection of the sample area to be analyzed, statistically process and measure

Table 2. List of instrumental analysis of beer from literature and European Brewers Convention (EBC) standards (Buiatti *et al.*, 2014).

Analysis	Principle of analysis	Reference method/References
Content in ethyl alcohol	Measurement of refractive index or enzymatic reactions (alcohol-free beers)	EBC methods: 9.2.1, 9.2.3, 9.3.1, and 9.3.2
Final attenuation	Yeast use of fermentable sugars	EBC method: 9.7
Bitterness	Absorbance at 275 nm	EBC method: 9.8
Color	Absorbance at 430 nm	EBC method: 9.6
Carbon dioxide	Pressure	EBC method: 9.28.1
Turbidity and cold turbidity	Nephelometric measurement	EBC methods: 9.29 and 9.41
pH		EBC method: 9.35
Foam stability	Measurement of foam collapse over time	EBC method: 9.42.1 and 9.42.2
Shelf life prediction		EBC method: 9.30
Oxygen content	Electrochemical measurement	EBC method: 9.37.1 and 9.37.2
Real extract	Saccharometric measurement	EBC method: 9.4
Fermentation degree		Park *et al.*, 2023; Zhao *et al.*, 2023
Viscosity	Ubbelohde viscometric measurement	Zhao *et al.*, 2023
∘Plato	Refractometric measurement	Zhao *et al.*, 2023
Total phenol content (TPC) and polyphenols	Measurement of absorbance at 765 nm	Anderson *et al.*, 2019; Singleton and Rossi, 1965
Antioxidant activity by two assays: 2,2-diphenyl-1-picrilidrazyl (DPPH) and 2,2′-azinobis-3-ethylbenzothiazolin-6-sulphonate (ABTS)	Measurement of absorbance at 517 nm and 734 nm	Anderson *et al.*, 2019; Zhao *et al.*, 2023; Zong *et al.*, 2022
γ-Aminobutyric acid (GABA)	Measurement of absorbance at 630 nm	Yu *et al.*, 2021; Zhao *et al.*, 2023
Volatile substances	Use of headspace solid-phase microextraction (HS-SPME) coupled with gas chromatography–mass spectrometry (GC-MS)	Wang *et al.*, 2022; Zhao *et al.*, 2023
Carbohydrates	High-performance liquid chromatography (HPLC) coupled with refractive index (RI), ultraviolet (UV), fluorescence (FLD), or mass spectrometric detectors; capillary electrophoresis (CE); ion chromatography/anion exchange chromatography coupled with pulsed amperometric detection (HPAEC-PAD)	Anderson *et al.*, 2019
Vicinal diketones (VDK) and fatty acids	HS-SPME-GC; MS; flame Ionization detector (FID); electron capture detector (ECD); and stir-bar solvent extraction (SBSE)	Anderson *et al.*, 2019
Organic acids	HPLC coupled with chemiluminescence (CL) and photochemical reactions	Anderson *et al.*, 2019
Iso-α-acids and mycotoxins	HPLC and HPLC-UV	Anderson *et al.*, 2019
Bacteria	Phenotypic identification; matrix-assisted laser desorption/ionization–time of flight (MALDI-TOF)	Anderson *et al.*, 2019

color variation using the selected models: hue saturation intensity (HSI) and red green blue (RGB). These color models are used to simplify and standardize colors (Cao *et al.*, 2019).

Biological quality (chemical composition and sensory) and process quality

Several factors influence the chemical–nutritional and sensory properties of beer, such as water pH and hardness, yeast strain, hop selection, malt type, temperature, oxygen levels, and fermentation duration. It is important to note that water composition, yeast, and hops significantly impact beer's flavor, aroma, and stability. For instance, water with a higher pH can result in smoother and well-rounded beers. Temperature during fermentation plays a crucial role in determining the flavor, aroma, and fermentation speed. Higher temperature promotes the production of fruity esters, while lower temperature results in cleaner and more neutral beers. Although oxygen is essential for initial yeast growth, excessive oxygen can lead to oxidation and hinder fermentation. Pre-fermentation wort oxygenation is essential for the desired effectiveness of yeast and the subsequent fermentation process. Lastly, body, complexity, and carbonation of beer are influenced by fermentation and maturation time. Beers with longer fermentation periods tend to be more complex (Micetcraft.com, 2021; Winning Beers, 2023). Following are the factors that influence the final impact that consumers have while drinking beer.

Brewing strategies influencing sensory characteristics in beer production: a focus on hopping methods, fermentation temperature, malt quality, and phenolic composition

The hopping method (boiling or dry), fermentation temperature (12–18°C) and yeast strain influence the sensory characteristics (bitterness, color, and alcoholic content), phenolic content, and volatile compounds of beers. According to different studies, hopping is the factor that influences the composition and sensory properties of beer (Algazzali and Shellhammer, 2016; Brendel *et al.*, 2019; Takeoka *et al.*, 1998). Hops are generally divided into two categories: bittering and aroma. Bittering hops have higher alpha acids, making them more cost-effective for bittering beer, as only a small amount of hops are required. Aroma hops, on the other hand, tend to have more essential oils, which contribute to the characteristic hop aromas, such as citrus, pine, mango, resin, and melon (people understand as 'hoppiness'). By adding hops early in the brewing process, the essential oils volatize and boil away, either during the boil or fermentation. Adding hops later in the brewing process tends to increase beer's hoppy aroma and make it smell 'hoppier'. However, heavily hopped beers may not retain their aroma and flavor over time. Aromas and flavors of hop-forward beer may dissipate, resulting in a different taste than intended by the brewer (Allagash Brewing Company, 2020; Food & Tec., 2023). Fermentation temperature has a significant influence on the content of phenolic compounds present in beers produced by boil-hopping (BH), but the beers produced by dry-hopping (DH) are characterized by a more floral and fruity aroma.

The roasted (toasted) character of beer is mainly derived from malt roasting and the beer type (style). In beer production, barley malt is roasted at different temperatures to obtain different flavors and colors. The intensity of roasted character increases with higher roasting temperatures, resulting in notes of coffee, chocolate, toast, and licorice. The commonly used roasted malts include caramel malt, which imparts amber color and light caramel aroma; chocolate malt, which gives brown color and dark chocolate taste; and roasted malt, which produces black color and coffee and licorice flavor. Some beers are naturally more roasted than others. Stouts and porters, for example, are dark beers that use a large amount of roasted malt, giving them an intense roasted character. In contrast, brown ales and amber ales use smaller amounts of roasted malt for a lighter roasted character (Baladin, 2023; BeerSmith™ Home Brewing Blog, 2022; Craft Beer & Brewing, 2006; Il Fatto Alimentare, 2023; Il Giardino delle Luppole, 2022).

Some authors have proposed alternative hopping methods to increase the volatility and hop aroma and to produce flavored beers, such as late hopping, whirlpool hopping, and hop back hopping (Lafontaine and Shellhammer, 2019). The three techniques consist of adding hops almost at the end of boiling, or just at the end of boiling when the wort is getting colder, but unlike dry-hopping, the temperature must be high (Food & Tec., 2023).

Concerning the phenolic composition of beers, it should be noted that they are mainly derived from malted barley and are found in free or bound forms and in concentrations of up to 50% lower than in the sweet product (Ferreira and Guido, 2018; Francesca *et al.*, 2023; Han *et al.*, 2023; Horvat *et al.*, 2019; Özcan *et al.*, 2018; Paszkot *et al.*, 2021). The use of roasted malt, in combination with proper milling, high mashing temperature, and low pH, results in the release of phenolic compounds due to increased extraction (Carvalho and Guido, 2021).

The major phenolic compounds in beer are hydroxycinnamic acids (e.g., *p*-coumaric and ferulic acids), flavan-3-ols (e.g., (+)-catechin and (-)-epicatechin), and oligomeric proanthocyanins (Humia *et al.*, 2019; Piazzon *et al.*, 2010; Tatullo *et al.*, 2016). Dark beers have phenolic levels of up to three times higher than other beer types because of the release of bounded phenolics during heat treatments and the increased extractability associated with grain friability. In addition, phenolic compounds can interact with melanoidins formed during malt roasting, improving their solubility and stability during production; therefore, milling grain can also increase phenolic extraction (Maldonado *et al.*, 2022). Acidity, alkalinity, and enzyme or water activity can induce phenolic extraction and these are the parameters controlled by brewers. Furthermore, production parameters, such as filtration and pasteurization for industrial beers, or hop drying for craft beers, are responsible for phenolic content. However, the fate of individual phenolic compounds during brewing is difficult to predict because they may undergo different processes (e.g., release, degradation, polymerization, adsorption, or precipitation). The total phenolic content in beer was found to be 50% lower than the sweet wort content because of significant heat loss during the clarification process, as polyphenols form a complex with proteins (Özcan *et al.*, 2018; Paszkot *et al.*, 2021; Wang *et al.*, 2022), as well as polyvinylpolypyrrolidone (PVPP) filtration, which is capable of removing large polyphenolic molecules that are precursors of astringent flavors (Ranatunge *et al.*, 2017).

In addition to traditional methods, new technological strategies for beer and malt production include the use of special yeasts, manipulation of enzymatic activity, and dry-hopping. These techniques could be of great importance in achieving adequate levels of phenolic compounds for the benefit of beer stability and consumer health. Several yeast strains are known to produce higher levels of phenolic compounds than others. For instance, the nonconventional yeast *S. cerevisiae* var. *diastaticus* has been demonstrated to enhance the concentration of volatile phenols that contribute to clove flavor in some wheat beers (Verachtert and De Troostembergh, 2002). Enzymes are essential in breaking down complex malt molecules into simpler components that yeast uses for fermentation by manipulating the activity of specific enzymes. Brewers can influence as well the production of phenolic compounds by manipulating the activity of specific enzymes. For example, increasing the activity of β-glucosidase, an enzyme that releases bound phenolic precursors, can lead to higher levels of free phenolics in beer (Li *et al.*, 2016), as studied widely in the field of oenology. Dry-hopping enhances the aroma and flavor of beer by introducing volatile hop compounds. Some of these are phenolics. For instance, dry-hopping with hop varieties, such as cascade or citra, imparts citrusy and tropical fruit aromas, which are derived from phenolic compounds such as myrcene and limonene (Klimczak *et al.*, 2023). Such strategies are crucial for achieving adequate levels of phenolic compounds in beer.

Alternative use of hops

Hop is a plant of the *Cannabaceae* family and is rich in volatile compounds that provide bitter and characteristic flavor (Brendel *et al.*, 2016; González-Salitre *et al.*, 2023). It is also composed of bioactive compounds, such as phenols, flavonoids, etc. Hops have shown functional and nutraceutical benefits, and therapeutic and pharmaceutical applications (Algazzali and Shellhammer, 2016; Brendel *et al.*, 2019; Gargani *et al.*, 2017; Knowledge Center Brew Up by the Brewers of Europe, 2019; Krofta *et al.*, 2008; Raihofer, *et al.*, 2022). Although boiling at a high temperature alters sensory profile and chemical structure by increasing bitterness, each hop variety provides a specific aroma, depending on harvest, genotype, climate, humidity, altitude, and irrigation. Therefore, in a previous discussion on hopping, aromatic hops are added before or after the fermentation process to reduce volatile losses (González-Salitre *et al.*, 2023). Owing to their health benefits, hops are also used in products other than beers (Il Giardino delle Luppole, 2022), although climatic crisis has reduced the production and cultivation of hops in main producing areas (Il Fatto Alimentare, 2023). At the September 2023 International Organic and Natural Exhibition (SANA) held at Bologna, Italy, the first exhibition in Europe dedicated to organic and natural products, hop-based preparation alternatives to the classic brewing sector stood out among various innovative products. In particular, a small agricultural company presented various products based on hops, fully valorizing the Italian production, such as pesto 100% with Romagnolo hops, hop sprouts, chocolate, taralli, and piadine flavored with hops (Il Giardino delle Luppole, 2022).

Addition of innovative ingredients in beers

The quality of beer depends on the activity of fermenting yeasts, such as *Saccharomyces cerevisiae* and *S. carlsbergensis* (*S. pastorianus*), which not only contribute to good fermentation yield-efficiency but also influence beer aroma, since most of the aromatic compounds are intermediate metabolites and by-products of yeast metabolism (Capece *et al.*, 2018). The selection of strains relies on their adaptability to the food product and the type of fermentation (González-Salitre *et al.*, 2023).

Brewer's *Saccharomyces* is typically categorized into two groups: ale and lager yeasts, also known as top-fermenting and bottom-fermenting yeasts, respectively. Originally, these strains were classified based on their flocculation properties. After fermentation, the ale yeast rises on the surface of the fermented wort, while the lager yeast settles down at the bottom of the fermentation vessel. The two types of brewing yeasts are also differentiated by their growth and fermentation temperatures. Although the optimum growth temperature for *Saccharomyces* is between 25°C and 30°C, the growth and fermentation of bottom yeasts are performed between 4°C and 12°C, and top fermenting yeasts prefer 14–25°C temperature (Capece *et al.*, 2018).

Although ale yeasts are used to produce beers with varying characteristic, such as ale, stout, or porter, the strains used for these beers belong mainly to *S. cerevisiae* species. However, beer strains within the *S. cerevisiae* group are more diverse than wine strains. It has been found that many top yeast strains in quality are hybrids. In fact, González *et al.* (2008) reported that 25% of the top strains found in Belgian Trappist beers may have resulted from hybridization between *S. cerevisiae* and *S. kudriavzevii*. The authors also demonstrated that beer yeasts have a high incidence of polyploidy and aneuploidy, which probably results in limited or no sporulation ability. Genome analyses and large-scale phenotyping of industry-specific traits have revealed that certain traits were selected during brewing yeast domestication. For example, yeast strains with a greater capacity to metabolize maltotriose were favored (Gallone *et al.*, 2016). Additionally, yeast strains with reduced production of phenolic off flavors were also selected.

Regarding yeast strains used in the production of lager beers and now assigned to *S. pastorianus*, the situation is more complex than with ale yeasts. It has been known for some time that bottom brewer's yeast strains of *S. pastorianus* are hybrids. Lager yeasts are actually classified as allopolyploid hybrids of *S. cerevisiae* and *S. eubayanus* (Dunn and Sherlock, 2008; Libkind *et al.*, 2011; Nakao *et al.*, 2009). A strain of *S. eubayanus* was first isolated in Patagonia, showing high identity (99.5%) with non-*S. cerevisiae*, part of *S. pastorianus* genome (Libkind *et al.*, 2011). *S. eubayanus* is known for its cold tolerance, which is directly correlated with the proportion of *S. eubayanus* genome (Gibson *et al.*, 2013). However, its tolerance to high ethanol concentrations is lower than that of traditional ethanol-producing strains.

Currently, the brewing industry is experiencing a growing need for innovative products. As a result, uncharacterized autochthonous starter cultures, spontaneous fermentation, or non-*Saccharomyces* starters are used more frequently for producing unique and unconventional products. In order to achieve products with more complex sensory characteristics, nonconventional yeasts, that is, non-*Saccharomyces* yeasts are explored. These strains are generally characterized by low fermentation yields and are more sensitive to ethanol stress, but they provide a distinctive aroma and flavor. Additionally, researchers have investigated the use of *de novo* interspecific hybrids created from different species within the *Saccharomyces* genus. The use of hybrid yeasts is associated with several aspects of beer fermentation, such as fermentation rate, aroma production, temperature tolerance, and sugar utilization (Krogerus *et al.*, 2017), and for producing low-alcohol beer (LAB), non-alcoholic beer, and light beer. Traditional and nonconventional yeasts in brewing, along with their wide selection, represent a new biotechnological approach to targeting beer characteristics and producing different or even totally new beer styles (Capece *et al.*, 2018). Other innovations pertain to packaging, especially to affect volatile and sensory profile, or the ingredients; some authors have reported the use of fruits, plants, or vegetables in beer production (Baiano, 2021). Tables 3 and 4 show some of the most recent innovations proposed by scientific teams.

Chemical profile of beer during storage

Monitoring the relative numbers of different classes of chemical compounds in beers provides information on the influence of chemical profile of beer during storage, specifically regarding temperature. Ferreira and Guido (2018) demonstrated that aldehydes, furan compounds, and esters play a key role in beers stored at 37±1°C. The rate of development of furan, aldehyde, and ester compounds was shown to be almost 140, 90, and 20 times higher, respectively, in beers stored at higher temperatures than in beers stored at 4±1°C. The study also showed that the chemical composition after 6 months of storage was significantly different from that of fresh beers. Furthermore, the hierarchical cluster analysis (HCA) indicated that storing beer at low temperatures is the optimal method for preserving the freshness and organoleptic characteristics of fresh beers. The temperature is detrimental to the development of certain 'stale' compounds, such as aldehydes, furan compounds, and esters, formed in beers stored at 37°C. Regarding olfactometric analysis, the presence of esters and aldehydes is correlated with fruity, herbaceous, and floral aromas. A significant difference was observed in aged beers, where the sweet and papery aromatic notes were dominant. The presence of β-damascenone is related to sweet aromas, while papery aromatic notes are related to the presence of (E)-2-nonenal. These two compounds, found only in aged beers, have been suggested as reliable chemical markers of beer aging (Ferreira and Guido, 2018; Ferreira *et al.*, 2022; Horvat *et al.*, 2019).

Temperature is a critical factor in storage of beer. Refrigeration helps to stabilize, extend shelf life, and preserve the quality of LAB. Physical and biological processes are used to produce beers with reduced alcohol concentration. In fact, alcohol is effectively removed by physical methods, such as thermal or membrane-mediated processes, from regular beer, resulting in very low levels of ethanol (through osmotic distillation,

Table 3. Use of new starter cultures in beer processing.

Innovation	Strain	Purpose	Country	References
Selection of microbial culture	*Lanchancea thermotolerans* strain (MNF105) isolated from manna for fruit sour beer production	Improvement of flavor profile and control of fermentation process	Italy	Francesca *et al.*, 2023
Selection of microbial culture	*Saccharomyces cerevisiae* strain (MN113) isolated from manna as a possible starter culture in fruit beer production	Improvement of flavor profile and control of fermentation process	Italy	Francesca *et al.*, 2023
Selection of microbial culture	Non-*Saccharomyces* yeasts with high β-glucosidase activity isolated from grapes	Enhance terpene-related floral flavor	China	Han *et al.*, 2023
Selection of microbial culture	*S. eubayanus*	Low-temperature growth, efficient maltose uses and production of desirable aroma compounds	Belgium, Finland, France, and the Netherlands	Gibson *et al.*, 2017
Selection of microbial culture	Sourdough cultures of non-*Saccharomyces* yeast species maltose-negative	Production of LAB and improvement of their typical 'worty' flavor	Finland and Italy	Johansson *et al.*, 2021
Hybridization	De novo yeast hybrids of *S. cerevisiae* ale strain and *S. cerevisiae* var. *diastaticus*/cold-tolerant *S. bayanus*/ Saaz-type *S. pasturianus*/ *S. eubayanus*-type strains	Increase of fermentation rate, improvement of aroma and osmo- and temperature tolerance, improvement in sugar utilization	Belgium, Denmark, Finland, Japan, South Korea, and the Netherlands	Krogerus *et al.*, 2017
Selection of microbial culture	Basidiomycetous psychrophilic yeast strain *Mrakia gelida* DBVPG 5952	Production of LAB	Italy	De Francesco *et al.*, 2018
Selection of microbial culture	*S. cerevisiae* DBVPG 6580 with amylolytic ability (isolated from a Brazilian bioethanol plant)	Production of low-carbohydrate beer with peculiar flavor using top-fermented method	Italy	Troilo *et al.*, 2019
Selection of microbial culture	*Saccharomycodes ludwigii* TUM SL 17	Production of cold-stored unpasteurized low-alcohol craft beers	Italy	Sileoni *et al.*, 2023

pervaporation process, etc.). The use of physical methods, however, requires breweries to make investments. In Italy, craft beer production is subjected to strict regulations that prohibit the use of microfiltration and pasteurization as stabilization methods (Legge 16 agosto, 1962 n. 1354). Therefore, biological processes are the most feasible means to produce LAB for craft breweries. The main bioprocesses for LAB are interrupted fermentation by *S. cerevisiae* or *pastorianus* strains and non-*Saccharomyces* strains. Non-*Saccharomyces* yeasts, which are unable to metabolize maltose, are used to obtain LAB, resulting in a lower amount of ethanol during the fermentation of brewing wort (Sileoni *et al.*, 2023). However, the instability of craft LAB is due to its weaker body, poorer flavor, and the concentration of oxygen in the headspace of bottles as well as the heavy pasteurization treatment required due to high residual sugars (Peña-Gómez *et al.*, 2020).

Cold chain is a practical option for small breweries that sell beer locally. LAB remains stable due to the yeast's protection from oxidation and its ability to reduce certain aldehydes. However, high oxygen levels in the headspace cause the beer to oxidize even at low storage temperatures and it is correlated with variations in flavor chemicals, such as aldehydes, higher alcohols, hops bitter substances, and ester contents (Sileoni *et al.*, 2023). Craft breweries use 'bottle refermentation' process that exposes beer to oxygen. To reduce oxygen concentration in unfilled space, several companies have developed oxygen-scavenging bottle caps. These oxygen scavengers have a liner that absorbs oxygen molecules in the headspace, preventing oxidation process and ensuring flavor stability while extending the shelf life of beer. Valentoni *et al.* (2022) demonstrated that temperature storage is the primary factor responsible for beer aging and its effect on accelerating oxidation processes, resulting in lost freshness, even when the cap is applied.

Role of microencapsulation in the chemical–nutritional composition, antioxidant power, stability, and level of approval of craft beer

Microencapsulation is used to concentrate and stabilize phenolic compounds in order to obtain a product with functional and healthy properties. Microencapsulation by spray-drying is used to produce microparticles of craft beer with the aim of obtaining a nutritious product

Table 4. Innovative ingredients in beer production.

Innovation	Matrix added	Fermentative method	Country	References
Substitution of barley and impact on sensory profile	Riceberry rice malt	Top fermented beer		Zdaniewicz *et al.*, 2021; Zhao *et al.*, 2023
Improvement of flavor, and nutritional and nutraceutical profiles	Red and blue corn and others pigmented cereals (blue, red, purple wheat grain, dark purple rice)		Mexico and Canada	Li *et al.*, 2007; Romero-Medina *et al.*, 2020; Zhao *et al.*, 2023
Uniqueness	Fruits ('Kriek' cherries or 'Framboise' raspberries), herbs, spices, vegetables	Belgian lambic beer	Belgium	Francesca *et al.*, 2023
Sour fruit beers	Loquat (*Eriobotrya japonica* Lindl.)		Italy	Francesca *et al.*, 2023
Sour beers	Fermentation carried out by yeast or bacteria: *Lachancea* spp., *Lactiplantisbacillus plantarum* (prev. *Lactobacillus plantarum*); *Brettanomyces* species; *Schizosaccharomyces japonicus, Hanseniaspora vineae*, *Lachancea fermentati*, *L. thermotolerans*, *Wickerhamomyces anomalus*; *S. cerevisiae* var *diastaticus*, *S. pastorianus; Saccharomycodes ludwigii*	Traditional styles (Berliner weisse, Belgian trappist, Flanders red ale); 'primary souring' sour beers; traditional saison, farmhouse ales, Belgian witbier, Brut IPA; LAB	Germany, Belgium and Flanders	Burini *et al.*, 2021; Osburn *et al.*, 2018; Serra Colomer *et al.*, 2019
Improvement of aromatic compounds	Wheat	Belgian witbier (unmalted beers), German Weissbier (malted)	Belgium and Germany	Bianco *et al.*, 2019
Improvement of aromatic compounds	Grape berries or grape must or grape pomace	Italian grape ale (IGA)	Italy	Mastrangelo *et al.*, 2023
'Oliba green beer' (gluten-free beer)	Olive extract, safflower concentrate, and spirulina	Bohemian Pilsner	Spain	Food & Tec., 2023
Modification of sensory characteristics	Jasmine flowers, oolong tea, sweet jam		China	Baiano, 2021
Substitution of hops	Sage (*Salvia officinalis*), dandelion (*Taraxacum officinale*), nettle (*Urtica dioica*)		China	Baiano, 2021

(Akbarbaglu *et al.*, 2019; Ferreira *et al.*, 2022; Horvat *et al.*, 2019). Beer microparticles produced with and without maltodextrin (MD) at 140°C, 160°C, and 180°C showed no differences in physical parameters. Only the antioxidant activity and its preservation showed significant differences in relation to the use of MD as an encapsulation wall material. Two formulations of beer microparticles were produced with (160°C) and without (180°C) MD because of their properties and differences in formulation and nutritional composition. All microparticles produced had good physical properties. Over 180 days of stability, no reduction in phenolic compounds was found and the antioxidant activity showed differences only in terms of color and activity water value. Both products were well accepted in terms of general characteristics, taste, and color, and maltodextrins-microencapsulated beers retained their distinctive flavor while reducing the level of bitterness. Microencapsulation technology can, therefore, be used to preserve the nutritional quality and taste of beer. Furthermore, this microencapsulated product is also used to test a possible beneficial and healthy effect, thanks to the high content of phenolic compounds present in beer powders (Maia *et al.*, 2020).

Tatasciore *et al.* (2023) proposed freeze-drying to overcome unpleasant off-flavors resulting from spray-drying of hop extract powder, although the authors registered a loss of phenolic compounds with a general dependence of success of treatment on the type of coating material (maltodextrin vs. gum arabic vs. maltodextrin/gum arabic mix).

Convenience and Commodities

Factors that influence the choice of beer

Different variables influence the choice of beer consumption over a drink from another beverage category. Choice of beer is addressed through the pairing of beer and food, which provides key aspects for future research in the field of consumer science and marketing. Both intrinsic and extrinsic attributes of the product alone do not usually have an effect on beer craving and beer choice behavior, but rather interact with other consumption variables, such as psychological, sociocultural, and biological. Social environment is also considered a key factor, as the decision-making process is completely different when comparing consumers' purchasing behavior, which leads to different results when present in different environments. Considering that some product and consumer variables interact differently depending on the location, it is likely that effective consumer profiling and segmentation vary depending on the region or country of origin (Aizenman and Brooks, 2008; Allison and Uhl, 1964; Barnett and Spence, 2016). Many studies have explored the existence of flavor-driven segments within the overall craft beer segment, with some declared that craft beer drinkers exhibit the characteristic craft beer preference (stronger and more complex flavors), while others exhibit a preference for less complex and more traditional flavors. The results confirmed previous findings that sensory attributes are less susceptible to the effects of extrinsic information than effective, emotional, and other nonsensory product judgments (Jaeger *et al.*, 2020, 2021).

Given that these are the issues essentially related to an economic goal, they are not addressed in this review, which is purely technical in nature.

Influence of packaging on beer quality

Improved packaging and rapid transportation facilitated the expansion of markets and made beer a global beverage. Despite the presence of alcohol, carbon dioxide, and low pH (three excellent natural preservatives), beer is a chemically unstable product and changes continuously during storage. The quality of beer is influenced by the type of packaging used, which is determined by the barrier properties of packaging material (Lorencová *et al.*, 2019). Among its many functions, the container must guarantee product's protection against external factors, such as chemical (exposure to gases, humidity, and light), biological (especially microorganisms), and physical (shocks and vibrations). Glass is ideal for extending the shelf life of beer because it is an inert material, impermeable to gases and vapors. Aluminum cans and stainless steel kegs are highly resistant to corrosion and provide an exceptional barrier to gases, moisture, and light (Lorencová *et al.*, 2019; Rizzo *et al.*, 2014). Even polyethylene terephthalate (PET), the most common polymer used for plastic bottles and kegs, provides excellent protection against gas and moisture permeation. Although the quality of modern PET is significantly higher than that used previously, studies continue to achieve results comparable to glass and metals in different matrices and environmental conditions (Rizzo *et al.*, 2014). In addition, plastic has a second disadvantage, that is, transfer of substances hazardous to health. Studies on water bottles have found formaldehyde, acetaldehyde, and antimony. Yet, the origin of these compounds has not been proved, given the complexity of the manufacturing process, including container itself, sealing resins, background contamination, processing steps, recycled PET, etc. (De Francesco, 2020). Different authors have reported the migration of substances from PET, particularly under inappropriate storage conditions (exposure to UV rays, high temperatures, and prolonged contact with liquid). In this context, it is important to elicit awareness of all actors in the supply chain concerning the correct storage of beer, especially that packaged in PET (Giornale della Birra, 2019).

Label as a comic strip

While beer labels are constantly renewed and enriched with new proposals, some breweries have turned their labels into a story. Following the success of Librottiglia, a product that combines wine tasting with the reading of short stories, the brand and product design agency Reverse Innovation has created Comic Beer (Giornale della Birra, 2020; Il mondo della birra, 2020). The label of each bottle is transformed into an original accordion booklet with funny illustrated strips to be read while sipping your beer. The first edition of Comic Beer included three stories by young Spanish illustrator Alberto Madrigal. They were informal but at the same time profound. They were good for practically any moment and worked very well with the concept of 'instant gratification': beer that warms up if it is not drunk in a reasonable amount of time, and comic strips that usually concentrate on complete story in a few frames (Il mondo della birra, 2020).

A recent study examined the role of extrinsic cues in generating sensory and hedonic expectations for beer. A total of 166 beer drinkers viewed realistic beer labels that varied in their color, design, labeled alcohol content, and sensory descriptor, in response to which they rated their expectations of bitterness, smoothness, sweetness, refreshment, beer color, body, and liking. As expected, label color, label alcohol content, and sensory descriptor had significant and replicable effects on consumer expectations, providing new insights into how labeling shapes expectations, and illustrating the disproportionate influence of different extrinsic cues (Blackmore *et al.*, 2020).

Using Food Choice Questionnaire (FCQ) to learn about millennials' attitudes toward craft beer

Food choices involve a complex interaction of considerations, and numerous factors play a role to choose the type of food (Chen and Antonelli, 2020). Completing an FCQ helps in understanding the motivations behind such choices. The study conducted by Rivaroli *et al.* (2022)

examined the relationship between millennials' attitudes toward craft beer consumption and the food choice factors using an FCQ to explore consumer priorities and concerns regarding this alcoholic beverage (Rivaroli *et al.*, 2022). An online survey was administered to five recent craft beer Facebook groups (craft beer enthusiasts, N = 273), including FCQ articles and articles assessing attitudes toward craft beer. Analyses were conducted after defining the structure of the FCQ that best described the sample, which indicated that sensory enjoyment, mood, and convenience (online) had a positive influence on respondents' attitude toward drinking craft beer; weight control, on the other hand, discouraged consumers' attitudes toward drinking craft beer. The results confirmed the validity of the FCQ and showed how craft breweries must consider these factors while designing their products and adapting their communication strategies.

A study of Mexican consumers sought to understand the effects of gender (men vs. women) and the type of consumption (craft vs. industrial beer) on mental representations of beer. Participants were asked to visually sort out a set of beers in the presence of brand and packaging. Gender differences were discovered in the sorting task, particularly in the number of groups used to sort out beers. An interaction effect was also established between gender and the type of consumption, highlighting the complex relationship that existed between consumers and beers (Gómez-Corona *et al.*, 2017).

Recently, our research group conducted a study on the development of scientific questionnaires through different media for the dissemination of beer culture and the overall quality perception (data not shown).

Conclusions

Beer is a beverage with a long history and significant commercial value. Its production and consumption are regulated by strict regulations and a complex production chain. In this context, scientific dissemination plays a crucial role in providing a complete and updated overview of the studies conducted in this field. In fact, beer is considered a healthy and genuine beverage if prepared with high-quality ingredients and in compliance with rigorous production standards. The current review discussed the importance of controlled production in enhancing the wholesomeness and authenticity of beer in both traditional and industrial processes. It also highlighted recent studies indicating that certain hop varieties could provide beer with antioxidant and anti-inflammatory properties. This information could encourage breweries to use these hops potentially in improving the health benefits of beer. The article analyzed emerging trends in the beer market, including the growth of the gluten-free and non-alcoholic beer segment as well as the interest in convenience and commodities. It also explored the implications of these trends on the production chain and the marketing strategies of brewing companies. Scientific dissemination plays a key role in promoting a conscious and informed beer culture. The authors emphasized the importance of communicating scientific knowledge about beer to the public, resulting in a better understanding of its nutritional, health, and production aspects. The review could make a substantial contribution to the growth of the beer industry by providing a comprehensive and up-to-date knowledge base for all stakeholders, such as researchers, producers, distributors, and consumers. The focus on wholesomeness, authenticity, overall quality preconditions, and scientific dissemination added a value to the entire production chain and beer culture as a whole.

Author Contributions

Riccardo N. Barbagallo: Conceptualization, Writing original–draft, Supervision, Review & Editing. Valeria Rizzo and Giuseppe Muratore: Conceptualization, Supervision, Review & Editing. Chiara A. C. Rutigliano: Conceptualization, Data curation, Writing original–draft.

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