

FRUIT-INFUSED BEER: BREWING TECHNIQUES, FLAVOUR DIVERSITY AND QUALITY EVALUATION - A REVIEW

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ABSTRACT

Beer, one of the ancient and most widely enjoyed beverages globally, is witnessing a growing popularity in the form of functional brews. Nevertheless, there is a constraint on conducting a study on the impact of incorporating functional adjuncts at different stages of the production process, and how this affects the physical, chemical, and sensory properties. The current study examines the ingredients employed and their degree of incorporation to produce a functional beer with bioactive compounds, improved antioxidant activity, and increased flavour. Beer has been a trend with the infusion of fruit in the form of pieces or extracts. In addition, these ingredients were effectively incorporated into a number of processes, including wort boiling, fermentation, maturation, and packaging, to improve consumer perception and highlight the related benefits of health, including the prevention of heart disease and stroke, as well as the improvement of bone density. This review identifies the use of various fruits to enhance the bioactive components in the beer and impart flavour in addition to providing aroma and taste in various forms.

Keywords: Fruit-infused beer; Brewing techniques; Fruit enzymes; Bioactive compounds; Antioxidant activity; Sensory assessment

INTRODUCTION

Beer, the most popular carbonated fermented alcoholic beverage is made from various ingredients such as fermented starches from barley malt, hops as a flavouring agent and various fruits to enhance the fruit flavour in the beer. *Saccharomyces* is the only microbe added to 99 per cent of beers on the earth; any other addition is viewed as a defect. Some beers, on the other hand, are becoming increasingly popular in all countries over the world. These beers are produced through the fermentation or aging process using self-sustaining, non-starter microbiota, uncharacterized "natural" starter cultures, or secondary, non-*Saccharomyces* starter cultures. The manufacturing process involves several processes, including malting, milling, mashing, extract separation, boiling and hop addition, removal of extract and hop residue, cooling and aeration, fermentation, separation of yeast from young beer, maturing, maturation, and packaging. The objective of the entire process is to convert the starches present in grains into sugar, extract the sugar by means of water, and subsequently employ yeast to ferment it, resulting in the production of a gently carbonated, alcoholic beverage. The result is a unique beverage, and it is a frequently consumed beverage globally. It is suitable for individuals who need to follow a gluten-free diet. Furthermore, these countries have the potential to produce beer using 42 different substitute raw materials, in cases where barley is not grown. A wheat beer, for example, might be infused with citrus fruits for a bright and tangy flavour or a dark brew could be complemented with cherries or plums for a deep and delicate flavour (Kawa-Rygielska et al., 2019; Morya et al., 2024). Fruit-infused beer has arisen as a separate and inventive segment in the constantly shifting context of the craft beer market. This blend of natural fruit flavours and traditional brewing techniques has resulted in a broad range of beers that challenge and expand our understanding of what beer could represent. A crucial choice that directly affects the end product's sensory profile, fermentation efficiency, and general quality is the choice of particular fruits and microorganisms for beer manufacturing. Scientific, functional, and sensory factors must all be taken into account while making this decision in order to guarantee a well-balanced, premium beer. While microbes like yeast and bacteria affect fermentation kinetics, metabolic byproducts, and microbial stability, fruits provide fermentable sugars, acidity, polyphenols, and aromatic compounds. Brewers may produce distinctive beers that appeal to consumers while preserving consistency and innovation by carefully choosing fruits and microorganisms.

The fruit's flavour and fragrance characteristics, which must enhance or compliment the base beer, play a major role in the selection process. The sweetness, acidity, bitterness, and aromatic complexity of various fruits varies. Citrus fruits, such as oranges, lemons, and grapefruits, for instance, contribute a zesty, refreshing flavour that is perfect for wheat beers and hop-forward types like IPAs. Berries like blueberries, blackberries, and raspberries add tannic depth, bitterness, and deep color to sour ales and wild fermentations. Stone fruits that add juicy sweetness and flowery flavours, such as peaches, cherries, and apricots, frequently go well with Belgian ales and farmhouse-style brews (Kawa-Rygielska et al., 2019). To properly investigate the perspective of fruit-infused beer, we're going to look at its historical context, flavour profiles, historical significance, and impact on the beer trade (Mittag, 2014). This article looks at a number of brewing methods for adding fruits to beer, including barrel aging with fruit components, fermenting fruit purées, and directly adding fresh or processed fruits. The final flavour profile is greatly influenced by the fruit selection, processing technique, and interactions with yeast, hops, and fermentation conditions. Various fruit types add distinct flavours, including sweetness, acidity, bitterness, and fragrance, which add to the beer's overall complexity. Physicochemical characteristics (such as pH, alcohol content, and color), sensory analysis (taste, fragrance, and mouthfeel), and stability testing to determine consistency and shelf life are some of the important factors that go into evaluating the quality of fruit-infused beer. Alcohol level and secondary metabolite synthesis, which contribute to the beer's distinct flavour, can be impacted by the interaction between yeast and fruit sugars during fermentation. To preserve product quality, oxidation hazards and microbiological stability must also be controlled. This article emphasizes how fruit-infused beer has the potential to be innovative, allowing brewers to produce unique goods that satisfy a range of consumer tastes. In order to refine these drinks while maintaining consistency and sensory appeal, advancements in brewing technology and quality control techniques are essential. Understanding brewing procedures, taste interactions, and quality evaluation methodologies will be crucial for creating fruit-infused beers that are stable, flavourful, and of high quality, as the market for these specialty brews expands.

Historical foundations

Beer has been linked to communal connections, celebration, relaxation or revolt for over 1000 years, depending on context and perspective. It is regarded as one of history's defining drinks, with the first known beer dating back to almost the fifth

millennium BC, making beer one of the world's oldest drinks (Poelmans & Swinnen, 2012). It is unknown whether beer was discovered or invented; still, ancient writings show that beer was a by-product of agriculture when nomadic tribes began settling down and domesticating the practice of harvesting wild grains following the last ice age, approximately 10,000 BCE. Beer styles have evolved into cultural ambassadors, representing their respective countries on a global scale. These events, which range from grand beer festivals in Europe to vibrant gatherings in Asia, highlight the diversity of beers and the customs associated with their consumption (Behre, 1999). George Hodgson's Bow Brewery in London, which was the primary source of porters for the East India Company, conducted several experiments to address these challenges. These included methods like transporting beer that had not yet undergone fermentation or beer concentrate (Cornell, 2003). Nevertheless, all previous attempts were unsuccessful until the 1780s, when Hodgson decided to market a beverage known as barley wine instead of porter. Known as "October beer," this beverage was produced with recently harvested hops and was often aged (Cabras & Higgins, 2018). This beer served as a perfect substitute for porter since the October brew underwent more maturation throughout its six-month journey from England. Preserved inside the vessel's hull, it not only survived but also underwent enhancement over that period. Moreover, it was a robust, light-coloured and invigorating beverage, which was particularly attractive (Eberts, 2007). Thus, a pale ale was created in its early stages. Through gradual modifications, the formula underwent changes, leading to the creation of many versions, one of which was a milder pale ale specifically crafted for the British market with the advent of commercial refrigeration in the late 19th century, the transportation of perishable commodities underwent a significant change, resulting in a decrease in the prevalence of Indian Pale Ale (IPA) (Cornell, 2010) nearly 200 years after the first creation of the IPA, Americans revitalized this beer style by introducing a new kind of hops known as Cascade hops. These hops were made available to the public in 1972 by the U.S. Department of Agriculture (Eberts, 2007). After a span of three years, the robust citrus essence of Cascade hops was incorporated into the first American pale ale, produced by Anchor Brewing Company in San Francisco and marketed as Liberty Ale. This product sparked a fervent interest in craft beer in the United States and played a significant role in the revival of IPAs. IPAs gained popularity in the United States and then became popular in Britain, their country of origin (Oliver & Colicchio, 2011). According to Nelson, (2005) fruits and herbs were traditionally added to beer for a variety of purposes, including flavour improvement and preservation. Brewers in historic Europe, for example, frequently utilized fruits like cherries, plums and apples to balance the harshness of beer and make it more pleasant. According to the findings of De Keersmaecker (1996) Lambic beer, which originated in Belgium's Senne Valley, is one prominent type with a long history of fruit infusion. Lambics are brewed spontaneously, enabling natural yeast and bacteria to mix with the beer. This method yields a sour and complex base beer, which is frequently mixed with fruits such as cherries (kriek) or raspberries (framboise) to make renowned Belgian fruit beers. The BJCP (Beer Judge Certification Programme) recognizes more than 80 distinct beer varieties. Additionally, there are only a limited number of beer categories that impose limitations on the usage of technical terms in a particular geographical area (Strong, 2015). Notable examples are Lambic, a beer variety that undergoes spontaneous fermentation and originates from a region located immediately southwest of Belgium, and Kölsch, a pale and lightly hopped lager that is only made by brewers in Cologne (Köln). Trappist and other comparable varieties, originating from medieval Normandy, France, are mostly prevalent in Western European nations that have adopted the monastery beer-making customs. Mittag (2014) examines the notable historical and geographical importance of several beer genres, such as Pilsners, Porters, Stouts, Pale Ales, India Pale Ales, Cream Ales, and Steam Beers.

Brewing technology

The implementation of various technologies in the production process of beer, aimed at minimizing losses and enhancing product effectiveness, leads to increased profitability and improved quality for the maker. The Industrial Revolution brought about the mechanization of brewing. The procedure was regulated more effectively by implementing the use of a thermometer and saccharometer. This practice was first introduced in Britain and thereafter followed by other European nations (Hayden et al., 2013). The progress in ice-making and refrigeration technologies throughout the late 19th century enabled the manufacturing of lager beers during the summer months. In the 1860s, Louis Pasteur, a French scientist, conducted research on fermentation and developed several microbiological procedures that are still employed in brewing to this day (Carvalho et al., 2023).

Emile Hansen, a Danish botanist, devised methods for cultivating yeasts in pure cultures, free from any contamination by other yeasts and bacteria. Continental lager brewers rapidly embraced this approach of using pure cultures, whereas British ale brewers were resistant to it until the 20th century. Simultaneously, German-style lagers, which undergo bottom fermentation using pure yeast cultures, became the dominant kind of beer across the Americas (Willaert & Baron, 2004).

The brewery model accurately forecasts changes in thermal energy demand from an industrial location and facilitates the modelling of energy consumption. Technology, production planning, heat exchanger surfaces, and heat supply management all have an impact on the modification of brewing energy demand profiles (Carvalho et al., 2023). Muster-Slawitsch et al. (2014) conducted a study on the modelling of energy demand profiles in order to enhance heat recovery planning and design of new energy supply equipment. Decreasing energy intensity in processes enables the use of smaller heat supply equipment, which helps to avoid losses while operating at less than full capacity. Utilizing the mashing process shows great potential for both recovering heat and providing low-temperature heat. It is important to retrofit heat exchangers in pre-existing facilities (Carvalho et al., 2023). The study conducted by Valentoni et al. (2023) shows that modifying mashing temperature profiles can improve the efficiency of the process, the quality of the wort, and the utilization of low-temperature heat. Future research will assess the influence of novel profiles on subsequent processing procedures and final taste in complete brews (Sinha et al., 2007). The yeast populations of *S. cerevisiae* US-05 and *S. cerevisiae* T-58 underwent evolution until they stabilized at a consistent level of ethanol production. During this process, the yeast strain *S. cerevisiae* US-05 exhibited the early fermentation stage, which entailed the introduction of *H. uvarum*. The initial population of *H. uvarum* in *S. cerevisiae* US-05 was 6.1 Log CFU/mL and it grew to 6.3 Log CFU/mL by Day 9. After a duration of 24 hours, it attained its peak value of 7.2 Log CFU/mL. Afterwards, the ratio decreased until the end of fermentation on the 14th day of observation, reaching a value of 7.0 Log CFU/mL. The samples collected from T-58 displayed the anticipated patterns of fermentation kinetics. The water used to soak rice has the potential to cause eutrophication in water bodies and contribute to water wastage, which can have a substantial impact on human health. An advancement in technology was utilized to reduce the necessity of soaking rice, while the inclusion of *Lactobacillus* was employed to counterbalance the general acidity. The concentration of biogenic amines was decreased by 27.16%, thereby improving the safety and quality of the product. The inclusion of esters led to a rise in the mellowness of the taste and a reduction in the necessary maturation period. Therefore, decreasing the alcohol concentration would improve the overall quality (Wei et al., 2017).

One of the oldest and most unique beer-making customs is lambic brewing, which has its roots in Belgium's Pajottenland. Lambic ferments spontaneously, which means that environmental bacteria and wild yeast drive the fermentation process, in contrast to modern brewing, which depends on regulated yeast strains. Craft beer aficionados strongly appreciate Lambic beers because of their distinctive acidic, funky, and complex flavour character, which is attributed to this special process. Lambic is brewed utilizing a traditional grain composition, which usually consists of at least 30–40% unmalted wheat and a mixture of barley malt. This combination adds to the beer's crisp acidity and hazy look. To optimize starch extraction, parts of the mash are taken out, heated separately, and then returned as part of a special turbid mashing technique. Slow, long-term fermentation is made possible by this method, which guarantees that the wort's unfermentable carbohydrates remain present (Carvalho et al., 2023). After that, the wort is boiled with matured hops for a long time, typically three to four hours. Aged hops, as opposed to fresh hops, are utilized mostly for their antibacterial qualities rather than their bitterness, which helps to keep out undesired microbial contamination while fostering the growth of natural souring bacteria. After boiling, the wort is moved to a coolship, which is a shallow open tank that is usually kept in an open-air brewery loft. This is an important step because it exposes the wort to the bacteria and wild yeast that are found in the environment. *Brettanomyces*, *Pediococcus*, and *Lactobacillus* are important microbial strains that start fermentation and give the beer its acidity, funk, and nuanced scent. The beer is moved to wooden barrels for a period of one to three years of slow fermentation and maturation after it begins. Frequently used for wine or spirits, the barrels contain extra microorganisms that contribute to the flavour of the beer. Remaining sugars continue to ferment as they age, acquiring earthy, fruity, and acidic characteristics. In order to produce a well-balanced and complex beer, the finished product frequently combines variously aged Lambics (Hayden et al., 2013).

Table 1 Different types of fruits, microbes, processing conditions and quality of beer

S.No.	Type of fruit/cereal used	Yeast species	Fermentation temperature and storage	Alcohol percentage (%)	Physio chemical parameters	Reference
1.	Dried Cape Gooseberry	<i>Saccharomyces</i>	18°C for 7 days & stored for 10 days room temp	6.13%	TPC – 318.62 Ph - 3.81 TSS - 5.97 °Brix	<i>Rinaldi et al., 2022</i>
2.	Black wheat	<i>Saccharomyces cerevisiae</i> CMS12	28°C for 120 hours	7%	Acidity – 0.27 Ph - 4.04 TSS – 1.3 °Brix	<i>Singh et al., 2023</i>
3.	Mango	Fermented yeast S33	25°C 10-14 days	5.8%	Bitterness-27.5 IBU Original wort- 14.2 °P	<i>Yin et al., 2021</i>
4.	Red grape pulp	<i>1.Dekkera druxellensis</i> 3429 <i>2.Metchnikowia pulcherrima</i> MG970690	20°C for 14 days	1. 6.16% 2. 6.90%	pH – 1) 3.95 2) 3.42 T.A – 1)7.44 2)7.67	<i>Cioch-Skoneczny et al., 2023</i>
5.	Grape	<i>Saccharomyces kl-V1116</i>	15°C for 4 weeks	5-6%	Polyphenol – 754.40 mg/L pH-5.3	<i>Veljovic et al., 2012</i>
6.	Grape must	<i>Saccharomyces</i>	9-10°C for days Later decreasing 0°C	5.0%	pH-5.2	<i>Veljovic et al., 2010</i>
7.	Passion fruit	<i>Saccharomyces c.safale S-04</i>	1)15°C 2) 22°C for 120 hours	1) 7.61% 2) 8.29%	TSS-1) 2.7 °Brix 2)1.3 °Brix pH-2.85	<i>Melo et al., 2017</i>
8.	Combination of Cherry, Raspberry, Blackberry, strawberry, elderberry	<i>Saccharomyces</i>	-	2.5–8.5 %	3.00 and 11.00	<i>Pérez-Alva et al., 2023</i>
9.	Pomegranate beer	<i>Dry yeast (Saccharomyces cerevisiae)</i>	-	4.56%	8.5	<i>Yensodsai, 2015</i>
10.	Dried cape gooseberry	<i>Saccharomyces cerevisiae</i>	18°C, for seven days	5.13 ± 0.08c, 5.73 ± 0.15b, 6.13 ± 0.06a	13.83 ± 0.15	<i>Rinaldi et al., 2022</i>
11.	yellow passion fruit pulp	<i>Saccharomyces cerevisiae</i>	Primary:15°C for 10 days Secondary:4°C for 15 days	4.50-4.70°GL	pH - 3.65-3.66, acidity - 0.33%, phenolic compound - 67-68 mg/100 mL, antioxidant activities-2.45-3.04 mM	<i>Dos Santos et al., 2022</i>
12.	Sea buckthorns	-	18 °C for 4 weeks	Alcohol strength 8.40 ± 0.73	pH - 5.8 ± 0.1 to 4.6 ± 01 foaminess 6.86 ± 2.20 color 7.92 ± 0.79	<i>Belcar & Gorzelany, 2022</i>
13.	Haskap (<i>L.caerulea</i> var. <i>emphyll ocahyx</i>) Along with Kamchatka Berries (<i>L. caerulea</i> var. <i>kamtschatica</i>)	<i>Saccharomyces cerevisiae</i> Ferments <i>Safale US-05</i> yeast in (6 × 10 ⁹ /g)	21 days at 21°C.	High ethanol content ranging an average of 14.06%	Average acidity 3.55–4.22 pH was 4.40–4.47	<i>Belcar et al., 2023</i>
14.	Jussara fruit (<i>Euterpe edulis</i> Martius)	<i>Dry yeast Safale US05 (Saccharomyces cerevisiae)</i>	8 days for fermentation	Ranging from 3.6% (w/v)	4.43 of pH	<i>de Brito et al., 2023</i>

Fruit incorporated beer

Fruit incorporation involves adding fruit in various forms- such as pulp, juice, and other processes- to enhance the aroma of the beer. Fruit beers are gaining popularity, especially in the craft brewing sector. However, microbial contamination from fruit peel and seasonal variations in fruit harvesting can affect consistency and yield. Fruit can be introduced as juice, pulp, or pieces during primary or secondary fermentation, according to *Daniels (1998)*. *Fanari et al., 2020* conducted an experiment to analyze the methodology of incorporating fruit into fruit beers during the production phase. According to *Croonenberghs et al. (2024)*, fruits are chosen according to their ideal developmental stage for efficient fruit juice extraction. Lambic beer, which ferments spontaneously and is aged in

oak barrels, is a specialty of Belgium. Lambic beer is used to make fruit lambic beverages, such as Kriek beer. Despite the lack of research on lambic beer-fruit co-fermentation, fruit beer has been around since the latter half of the 17th century. Without co-fermentation, these beers resemble market-driven, sweet, fruit-flavoured beers. *Nardini & Garaguso (2020)* quantified various compounds in fruit beers created by incorporating fruits during the fermentation process. They analysed antioxidant activity, total phenolic content (TPC) and total flavonoid content (TFC). Furthermore, the analysis indicated that all of the fruit beers examined had a rise in catechin and quercetin contents. The majority of fruit-infused beers contain both resveratrol and myricetin. Fruit beers generally exhibit higher levels of caffeic, chlorogenic, p-coumaric, and neochlorogenic acids compared to regular beer as shown in Table 1.

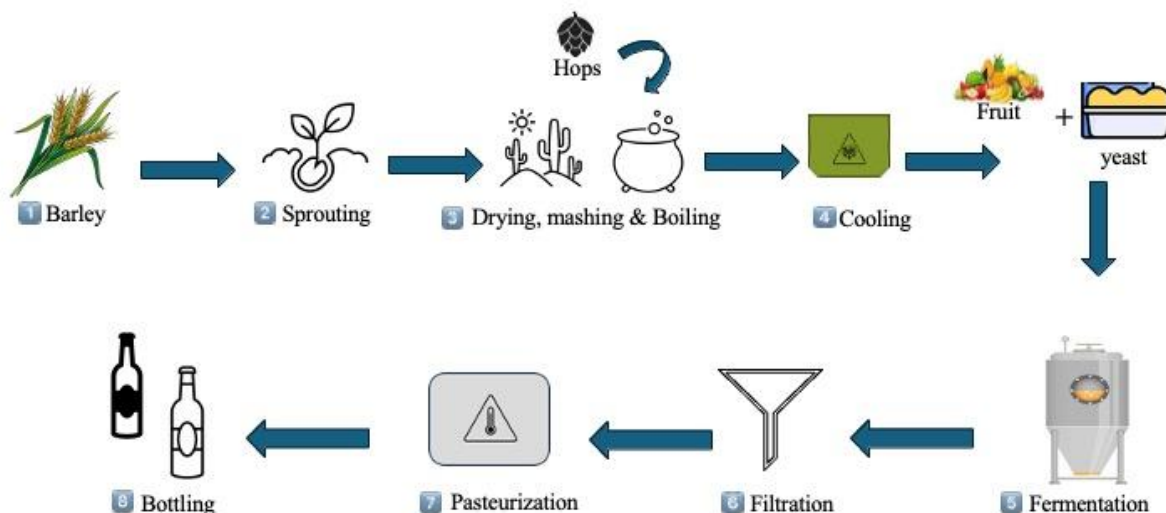


Figure 1 Flow chart for the representation of the infusion of fruit in beer

To improve beer quality and sensory complexity, the craft brewing sector continually adopts new technologies. Biotransformation, a process wherein yeast and microbial enzymes alter fruit-derived chemicals during fermentation to improve stability, flavour, and aroma, is one such creative method. This approach is especially useful in fruit-infused beer, as the organoleptic qualities of the finished product can be greatly impacted by the interplay between fruit phytochemicals and yeast metabolism (Fanari et al., 2020). Biotransformation occurs when fruit-derived precursors are converted into active aroma and flavour components by enzymes such as β-glucosidases, esterases, and cytochrome P450s. Fruity and flowery qualities can be enhanced by these enzymatic processes, which can release bound volatile thiols, terpenes, and esters. For example, certain yeast strains can enhance lemony and tropical notes by converting glycosylated monoterpenes in citrus fruits into free monoterpenes. Hydrolysis of glycosidic precursors in berries and stone fruits can enhance fruity and jammy aromas (Dos Santos et al., 2022). Fruit-infused beers benefit from the development of rich and well-balanced flavour profiles thanks to biotransformation. Brewers can manipulate the creation of desired volatile compounds by choosing particular strains of yeast. For instance, non-*Saccharomyces* yeasts like *Brettanomyces* can add distinctive pineapple, peach, and funky qualities by esterifying and oxidizing fruit components, while other strains of *Saccharomyces cerevisiae* are known to increase fruity esters. Additionally, during fermentation, the presence of precursors generated from hops may interact with fruit molecules, enhancing the aromatic depth (Croonenberghs et al., 2024).

Biotransformation affects mouthfeel and beer stability in addition to scent and taste. By altering the beer's colloidal structure, the enzymatic breakdown of fruit polysaccharides can enhance body and texture. Furthermore, certain yeast strains generate glycerol and other polyols, which improve the smoothness and lessen the astringency of beers with fruit infusions. Additionally, the breakdown of harsh-tasting substances, including fruit skin tannins, results in a more complex and well-rounded sensory experience. Biotransformation can help stabilize fruit-infused beer by reducing oxidation problems. As antioxidants, several yeast enzymes lower the possibility of color deterioration and the development of an off flavour brought on by oxygen exposure. Microbial interactions during fermentation can inhibit spoilage bacteria, prolonging shelf life without compromising flavour (Fanari et al., 2020; Morya et al., 2024). By experimenting with regulated enzymatic treatments, genetically modified yeasts, and mixed fermentations, brewers are increasingly utilizing biotransformation. A promising development is the

application of bioengineered yeast strains intended to maximize ester production and thiol release. Additionally, co-fermentation with *Lachanea thermotolerans* and other non-traditional yeasts can enhance natural acidity and fruit expression (Croonenberghs et al., 2024, Shahada et al., 2023). Brewers can adjust fermentation settings to produce desired sensory profiles as microbial biotransformation research advances. Customizing fruit components, fermentation conditions, and yeast selection offers a fascinating approach to create inventive, premium fruit-infused beers. Ultimately, biotransformation is a revolutionary technique that ensures improved beer quality, stability, and flavour diversity in an increasingly competitive market.

Benefits of fruit enzymes

Fruit enzymes are essential for improving health aspects by breaking down the compounds present in fruit, which contributes to the pleasant taste of the fruit. Enzymes can be classified as either endogenous (naturally occurring) or exogenous (commercially produced) (Tiwari et al., 2016). In brewing, malted barley provides the majority of the enzymes required for the process by breaking down starch into simple sugar before fermentation. Additional sources of starch (known as adjuncts) are commonly utilized for increasing the amount of convertible sugar and decreasing the comparative expenses associated with fermentation. According to Goma Ahmed (2018) determined β-glucanase, protease, α-amylase, and β-amylase are the four enzymes most commonly employed in the brewing process. Brewing enzymes are necessary for the process of converting starch into sugar (using bacterial and fungal α-amylase), breaking down barley glucan molecules (β-glucanase), and hydrolyzing proteins (neutral protease). These enzymes are used to enhance the frequency of yeast fermentation, especially in the production of high-gravity brews, which involves the addition of extra protein. Bamforth et al. (2009) stated that cellulases are sometimes used, especially wheat can be added as an adjunct, to assist in the degradation of barley β-glucans because of the high thermal stability of *Bacillus amyloliquefaciens* α-amylase, the wort needs to be boiled for a significantly extended duration to deactivate it before fermentation. Papain is employed during the final stage of beer production- specially in the post-fermentation phase, to inhibit the development of 'chill-haze', which consists of proteins and tannins interactions. This haze typically appears after the beer has been chilled.

Table 2 Enzymes present in the fruit and their benefits in health

S.No.	Fruit	Enzyme	Benefits	Flavour Profile	Reference
1.	Papaya	Papain	Anti-oxidant rich Clarifying cold beers	trifluoro nonyl acetate and trifluoroacetate-trans-2-dodecen-1-ol	Leitão et al., 2022 Zhou et al., 2021 Jing et al., 2015
2.	Kiwi fruit	Actinidin	Blood sugar control	2-cyclohexen-1-one, (E,E)-2,6-nonadienal, diethyl succinate, 2-ethylfuran, 3-methyl-1-butanol, methyl hexanoate ,methyl butanoate ethyl butanoate and hexyl hexanoate	Siddique et al., 2015 Jing et al., 2015 Jordán et al., 2002
3.	Pine apple	Bromelain	Rich in Antioxidants & Reduce the risk of cancer	methyl hexanoate, methyl 3-(methylthio)-propanoate, methyl 2-methylbutanoate ,methyl butanoate, , ethyl hexanoate and ethyl 3-(methylthio)-propanoate	Lobo, 2017 Elss et al., 2005 George et al., 2023
4.	Fig	Ficin	Blood cholesterol	isocaproic acid, 1-hydroxy-2-propanone, benzaldehyde, pentyl-alpha-furoate and 2-ethyl-Hexanol.	Hussain et al., 2021 Gündeşli et al., 2020 Crisosto et al., 2010

5.	Mango	Amylases	Breaking down starch into sugars such as glucose and maltose	γ -octalactone, 1-octanol, (<i>E,Z</i>)-2,6-nonadienal, Phenylalanine and methionine	<i>Lauricella et al., 2017</i> <i>Sung et al., 2019</i> <i>Sato et al., 2021</i>
6.	Avocado	Lipase	Breakdown of Fatty acids And Glycerol	Acetaldehyde, methyl acetate, pentanal, β -myrcene, β -copaene, α - and β -cubebene a cadinene isomer, α -farne-sene ,octane, decenal and heptenal	<i>Duarte et al., 2016</i> <i>Pereira et al., 2013</i> <i>Obenland et al., 2012</i>
7.	Grape pomace	Tannase, Cellulase, and Pectinase	Control of diabetes and Inducing agent of cancer cells	1-Pentanol , 3-Methylbutan-1-ol and 1-Butanol	<i>Meini et al., 2021</i> <i>Liang et al., 2020</i> <i>Brazinha et al., 2014</i>
8.	Cape fruit	Isothiocyanates	Metabolic syndrome Type 2 Diabetes Triglycerides, Low density lipoprotein cholesterol (LDLC) and High density lipoprotein cholesterol (HDLc)	<i>p</i> -menth-4(8)-ene-1,2-diol 1- <i>O</i> - α -l-arabinopyranosyl-(1-6)- β -d-glucopyranoside (2) and (1 <i>S</i> ,2 <i>S</i>)-1-phenylpropane-1,2-diol 2- <i>O</i> - β -d-glucopyranoside (1)	<i>Perna et al., 2023</i> <i>Ramadan et al., 2015</i> <i>Mayorga et al., 2001</i>
9.	Blackberry	Prolidase	Anti-inflammatory, Antiviral, Antiproliferant	3-methyl-1-butanol ,3-methyl-butanal, <i>trans</i> -furan linalool oxide and phenylacetaldehyde.	<i>Kaume et al., 2011</i> <i>Falcao et al., 2012</i> <i>Georgilopoulos & Gallois, 1988</i>
10.	Mulberry	Tyrosinase	Neuroprotective, Antiatherosclerosis, Immunomodulative	3-mercaptohexanol ,benzaldehyde, (<i>E</i>)-2-nonenal, ethyl butanoate, 3-mercaptohexyl acetate, hexanal, 1-hexanol and methional	<i>Yuan & Zhao, 2017</i> <i>Zhu et al., 2018</i> <i>Chen et al., 2015</i>

Flavour diversity and aroma profiles

The purpose of adding fruit is to enhance the characteristics of the beer. Breakdown of thiols originating from cysteine or glutathione-linked attachments, along with the liberation of terpene alcohols bound by glycosidic bonds, exhibits distinctive features. The objective of these modifications is to boost the fruit and floral aromatics in alcoholic beverages (*Castro Marin et al., 2021*) and facilitate the necessary preparations. Also, these can be analysed using GC-MS, and HPLC-MS along with sensory analysis to identify the total phenolic and aromatic components, as well as their sensory qualities. cv. Lambrusco grapes were added for demonstrating to enhance the colour, acidity, phenolic, and volatile components of beers. The work by (*Parkin & Shellhammer, 2017*) has brought attention to the sensory and analytical role of yeast in the biotransformation of taste components during beverage fermentation. This is especially true in the brewing industry, given the continuous popularity of pleasant beers generated by the dry-hopping process. The study conducted by (*Takoi et al., 2010*) investigated the biotransformation processes facilitated by yeasts capable of fermenting reactions that include a broad range of processes, including the formation of glutathione or cysteine attached conjugates by the breakdown of thiols, followed by release of terpene alcohols that are bonded glycosidically. This is because thiol molecules, which are formed by yeast amylase activity, have low taste thresholds, making them particularly sensitive to this. The contribution of yeast-glucosidases to the production of terpene alcohols is not clearly understood, particularly in the context of brewer's wort fermentation. (*Haslbeck et al., 2018*). The quince beers demonstrated greater concentrations of certain volatile compounds, such as methyl benzoate or ethyl hexanoate. Quince beers were found to have the lowest levels of 4-ethyl guaiacol, ethyl dodecanoate, and isoamyl octanoate, which are compounds that contribute to the perception of smokiness, floral aromas, and green flavours, respectively. When comparing different quince samples, it was observed that they had a higher concentration of compounds associated with fruity, sweet, and citric sensory characteristics (*Zapata et al., 2019*). The study examines the effects of incorporating ripe persimmon fruit on the sensory characteristics and antioxidant capacity of beer. Reactive oxygen species (ROS), such as hydrogen peroxide, hydroxyl radical, and singlet oxygen, are mostly generated from superoxide anions. They induce oxidative damage to lipids, proteins, and nucleic acids. The persimmon fruit had a noticeable effect on the beer samples' capacity to remove hydroxyl radicals. Hydroxyl radicals are highly reactive free radicals that occur spontaneously in biological systems. Therefore, the beer infused with persimmon, which has a significant capacity to neutralize harmful free radicals, has the potential to function as a protective agent against them. The beer samples showed a substantial increase ($p < 0.05$) in total polyphenol content, which was directly related to the amount of fruit present. (*Cho et al., 2018a*)

Nutritional and health implications

The addition of fruits to the beer during fermentation enhances its flavour. Mainly, beer is usually made with grain, water, and hops; this low-alcohol beverage is fermented using yeast. More than 2,000 different types of healthy elements are included in it (*Harold et al., 1961*). Beer can promote anti-cancer activity, lower the risk of diabetes and hypertension, and increase the absorption of dietary fibre when consumed in moderation. The process described produces a blended beer rather than a beer that has undergone fermentation with additional substances (*Costa et al., 2019*). Fruit extract, or in any form can be incorporated either before or within the fermentation process. To identify the optimal method for enhancing the beer's aroma, the mixture was flavoured with five distinct types of mango fruit.

A study of the volatile constituents in mango brew revealed that the beer lacking mango had the lowest concentration of volatile compounds, quantified at 1787.84 $\mu\text{g}/100\text{ mL}$. Consuming mango fruit along with beer increases the levels of several compounds, such as humulene, β -pinene, caryophyllene, terpinolene, α -pinene, α -terpineol, and cis- β -ocimene. The mango beer including more mango pulp had the greatest concentration of volatile compounds, measuring 2112.15 $\mu\text{g}/100\text{ mL}$. Beers that were infused with mango showed enhanced antioxidant activity and higher polyphenol content, surpassing the control beer by up to 44% (*Gasinski et al., 2020*). The properties of brewed beer made from Cornelian cherry include its physicochemical composition, content of iridoids along with polyphenol, and its antioxidant activity. The beer samples had a range of total polyphenol content, varying from 398.1 to 688.7 mg GAE/L. The Cornelian cherry cultivar had the most significant antioxidative activity, as demonstrated by the FRAP and DPPH% assays. Organic acid was the most frequent compound among the iridoids that were found. The beverage was infused with the original flavour of the coral fruit. The Cornelian cherry variety exhibited the most substantial concentration of organic acid, at 184.6 mg LA/L of beer. Anthocyanins and flavanol derivatives were among the polyphenols that were detected (*Gasinski et al., 2020*).

Oxidative stress has been linked to a range of health issues, including diabetes, atherosclerosis, neurological disorders, the ageing process, and malignancy. Consuming dietary antioxidants may reduce the harmful effects of oxidative stress. Polyphenols, which are found in almost all fruits and vegetables, are the primary dietary antioxidants. The amount of polyphenols consumed can differ according to the kind of food, and it can reach several hundred milligrams per day (*Olaniran et al., 2017*). This number far surpasses the use of other antioxidants, such as vitamin E, vitamin C, and beta-carotene. The nutritional quality of beer is significantly influenced by its antioxidant activity, which is further enhanced by its low ethanol content. Studies have demonstrated that consuming beer can enhance the antioxidant and anticoagulant actions in the bloodstream, while also improving cholesterol levels in humans. Moreover, studies have demonstrated that consuming beer in limited quantities can provide a safeguard against cardiovascular risk factors (*Nardini & Garaguso, 2020*).

While there may be some social and physical benefits to moderate beer drinking, excessive consumption can have detrimental effects on society and pose major health risks. One of the biggest issues is alcohol addiction and dependence, as long-term excessive drinking can result in alcohol use disorder (AUD), which is typified by compulsive drinking, withdrawal symptoms, and an inability to control alcohol intake. Another significant concern linked to excessive beer intake is liver damage. Long-term alcohol consumption can seriously damage liver function by causing cirrhosis, fibrosis, alcoholic hepatitis, and fatty liver disease. In a similar vein, excessive alcohol consumption raises the risk of cardiovascular conditions like hypertension, arrhythmias, and heart failure (*Ballance, 1961*). Anxiety, depression, and cognitive deterioration are among the mental health conditions that are associated with excessive beer intake. Alcohol alters the balance of neurotransmitters in the brain, which over time causes mood swings, memory loss, and a decline in cognitive performance. Chronic alcohol consumption is also linked to a higher risk of neurological conditions, such as dementia. Because beer is high in calories and can cause metabolic imbalances, excessive beer intake adds to weight gain and obesity in addition to the threats to personal health. Additionally, it impairs immunity, increasing the body's vulnerability to diseases and infections. From the standpoint of society, excessive drinking can lead to violent crimes, including domestic abuse and drunk driving incidents, reckless behavior, poor judgment, and accidents. Moderation and responsible drinking practices are essential for preserving general health and well-being in light of these hazards (*Rinaldi et al., 2022*).

Sensory and other quality assessment

The quality and sensory attributes of beer can be analysed by the physical appearance such as the colour, haze of beer and the taste of the beer with infused fruit as it increases the aroma of the beer. In dried cape gooseberry beer (Rinaldi et al., 2022) is prepared with an alcoholic strength of 6.13%. Star fruit (*Averrhoa carambola*) enriched with juice at concentrations of 5.0%, 7.0%, and 10% was produced. The reference sample had the most prominent concentration of alcohol groups, which lowered as the amount of the juice increased since it provides fortification and enhances the nutritional content and sensory aspects of the beverage. (Pal et al., 2022). The incorporation of Aronia berries at different stages of beer production can affect antioxidants, colour and pH (Ballance, 1961). The overall phenolic content remained unaffected by the number of Aronia berries introduced. However, both the EBC values and antioxidative capabilities were modified by both the quantity of Aronia berries added and the timing of their addition. In order to maximize the antioxidant capacity and minimize the colour intensity of the final product, it is advisable to include Aronia berries prior to the boiling process. Alternatively, if one wants to enhance the colour and antioxidant capacity, it is recommended to incorporate Aronia berries into the bitter wort, while it is still hot before it cools down. This method also helps to reduce the perception of astringency (Jahn et al., 2020). Barnette and Shellhammer (2019) examined the manner in which dissolved oxygen in dry-hopped beer affects the sensory perception and volatile characteristics of hops as time progresses. The beer was aerated to create beers with varying levels of concentration and thereafter stored either in a chilled environment or under accelerated circumstances.

The study conducted by Baert et al (2015) Based on the sensory study, it was found that the storage temperature had a greater impact on the aroma compared to the amount of dissolved oxygen. However, the influence of dissolved oxygen was still present at both high and low temperatures after a two-week ageing period, but to a lower extent. Rising temperatures, along with higher amounts of dissolved oxygen, led to a decrease in tropical, citrus, and hoppy characteristics, while encouraging the emergence of malty, dried fruit flavours. The amounts of monoterpenes derived from hops were not significantly affected by changes in treatment temperature or dissolved oxygen, suggesting that the manifestation of aromatic traits may be ascribed to other sources. The beer treated with persimmon showed a notable increase in antioxidant activities compared to the control, as assessed by the scavenging capabilities of DPPH. The levels of superoxide and hydroxyl anions, as well as the quantities of total polyphenols, exhibited significant differences ($p < 0.05$). The concentration of the mineral constituents in the persimmon beer exhibited a statistically significant increase ($p < 0.05$) in the amounts of magnesium, potassium, and calcium. Additionally, no harmful heavy metals were discovered. The overall acceptability rating experienced a considerable rise ($p < 0.05$) when persimmon beer samples were created by combining 150 grams of the fruit with 10 litres of water. The study by Cho et al. (2018) found that including 150 g of persimmon fruit per 10 units of water can enhance the beer. The bottled beers were subjected to maturation in a controlled atmosphere at a temperature of 40 degrees Celsius, with no exposure to light, and under forced conditions (Blanco et al., 2016). The antioxidant capacity was evaluated by conducting ferric reducing antioxidant power (FRAP) and DPPH radical scavenging activity assays at regular intervals of 0, 3, 6, 9, 12, and 15 days during the process of forced ageing. The materials were evaluated for their ability to scavenge radicals. Beer manufacturing may greatly increase the levels of beneficial compounds, including phenolic acids, rutin, and ellagic acid, among others. Integrating dried fruits into the brewing process has the capacity to safeguard beer consumers from a range of ailments, including cancer, cardiovascular disorders, osteoporosis, type 2 diabetes, and degenerative diseases. The chemical makeup of these substances is influenced by the timing of adding dried fruits. Ale beer has the highest level of resistance to oxidation and possesses exceptional sensory qualities. According to Yin et al. (2021), adding dried fruits significantly improves the colour of the beer.

Future directions

Brewers have access to a wide range of equipment, which continues to shape trends and improve the sustainability of beer production through emerging technology. The hop oil and flavour compounds, along with fruit content in beer can be influenced by various factors, including the quantity, type, and timing of hop addition. Additionally, specific biotransformation activities facilitated by yeasts during fermentation can also impact the fruit composition. Research into the use of fruits in the brewing process is a recently new area of exploration. The surge in popularity of craft beer in Asian markets, as well as in nations such as South Africa, Australia, New Zealand, and Brazil, can be attributed to the growing demand among consumers in these regions. The category experiencing the fastest growth remain unchanged.

CONCLUSION

Functional beers offer significant potential in the field of food science for delivering beneficial health effects. They entail the incorporation of supplemental adjuncts and additional processes. The addition of fruits to the boiling process promotes the extraction of phenolic and bioactive components, resulting in an

increased total phenolic content and antioxidant activity. Beer that includes fruits during the boiling process achieves a greater extraction of volatile compounds, leading to a favourable sensory experience. Plant extracts are mostly present throughout the maturation process, leading to a reduced amount of antioxidants and phenolic compounds. Research suggest that bioactive ingredients can be retained while also achieving favourable sensory properties, as most specially formulated beers receive equal or higher ratings in sensory evaluation. To analyse the bioactive chemicals, present in the beverage, advanced procedures such as LC-MS, which is at the forefront of technology, are required. A comprehensive study is required to determine the appropriate methods and types of adjuncts to be incorporated, taking into account factors such as physicochemical properties, sensory attributes, and physiological effects, including bioavailability. Functional beers present a significant and productive area for new research in the field of beer science. Further clinical research is required to comprehensively grasp the health and environmental consequences of beer, as well as the financial impacts of physical, chemical, and biological pollutants. The combined impact of specific pollutants, such as biogenic amines and ethanol, must be acknowledged and dealt with accordingly. The most hazardous risk associated with beer is chemical pollution, which arises from the inappropriate utilisation of chemicals for promoting biological growth and facilitating biotransformation. The regulation governing the permissible threshold of impurities in beer differs among nations, although all governing bodies give utmost importance to human well-being, the quality of ingredients, and the interests of beer manufacturers.

Author contribution

Pappoppula Hemanth- Conceptualization, Writing original draft, Review and Editing. **Mamata Ghosh**- Review and Editing. **Masuma Rahman**- Resources and Editing. **Sonia Morya**- Resources, Review, **Vinay Kumar**- Review and Editing, **Sourabh Kumar**: Conceptualization, Writing – review and editing, Supervision.

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