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Review

Functional Beer—A Review on Possibilities

Kristina Habschied [1,*], Antonio Živković [2], Vinko Krstanović [1] and Krešimir Mastanjević [1]

[1] Faculty of Food Technology Osijek, J.J. Strossmayer University of Osijek, F. Kuhača 18, 31000 Osijek, Croatia; vkrstano@ptfos.hr (V.K.); kmastanj@gmail.com (K.M.)

[2] Faculty of Economics in Osijek, J.J. Strossmayer University of Osijek, Trg Lj. Gaja 7, 31000 Osijek, Croatia; antonioziv1@gmail.com

* Correspondence: kristinahabschied@gmail.com; Tel.: +385-31-224-300

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Abstract: The expansion of the beer industry has enabled many possibilities for improvement regarding the taste, aroma and functionality of this drink. Health-related issues and a general wish for healthier lifestyles has resulted in increased demand for functional beers. The addition of different herbs or adjuncts in wort or beer has been known for centuries. However, today's technologies provide easier ways to do this and offer additional functional properties for the health benefits and sensory adjustments of classical beer. Medicinal, religious or trendy reasons for avoiding certain compounds in beer or the need to involve new ones in the brewing recipe has broadened the market for the brewing industry and made beer more accessible to consumers who, till now, avoided beer.

Keywords: functional drink; health; sensory properties; targeted consumers

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1. Introduction

Beer is considered as a nutritious and refreshing carbonated beverage, which is why its production is spread all over the world. The history of beer reaches far back to the ancient times, where the Sumerians, Babylonians and Egyptians brewed a very simple drink made of damp cereals left to germinate. With the addition of water and leaving for the spontaneous alcoholic fermentation to take place, a beer was brewed. Rich in minerals and vitamins, this alcoholic drink gained popularity very soon after it was first discovered. Due to its nutritive value, it could be considered as a functional beverage of ancient times. Through history, beer has always been a source of energy and nutrients, and boiling/cooking caused it to be healthier than water. Today's term defining "functional food or drink" refers to a non-alcoholic drink product whose constituents include herbs, amino acids, vitamins, minerals, and crude vegetables or fruits that provides health benefits beyond its nutritional value [1–3]. The beverage industry that produces "functional beverages" aims to allow the consumers the enjoyment of a drink with an added function. This function is often related to health-improving properties acting beneficially for the overall human body. Today's consumers are commonly trying to reduce alcohol, gluten, sugar, and carbohydrates in beer but without reducing its native taste [4]. The beer industry took the opportunity for expansion and is constantly making progress in fulfilling the consumers' desires. Big brewing industries are leading this trend, but small craft breweries also tend to participate. This review aims to describe the marketing strategies and research interests for the formulation of functional beers but also to relate its function with consumers' desires [4].

2. Marketing Strategy

The general scheme of supply and demand is the focal point of every industry. Today's consumers often tend to look for products that can help them in their everyday lives, make them easier and, when it comes to the food and drink industry, make them healthier. The growing demand for quality improvement among consumers has led to the evolution of the adjusted health-related functionality of beer. Religious factors are also an important part of this strategy.

In order to create a great demand for functional beer, different marketing strategies had to be created to satisfy consumers' wishes and needs. In its own beginnings of creation, the functional beverage had to be presented to the modern market—in other words, to the consumer, as something entirely new and authentic. One of the ways to do so is to completely separate the product from the competition in terms of originality and, of course, to connect the brand with the emotional story of the product. This could work for getting through to groups of consumers who want to turn their lifestyles in healthier directions or are bound to avoid certain food components such as gluten [5]. Likewise, it has a great impact on religious groups that are forbidden to consume alcoholic beverages. However, with the appearance of functional beer on the market, they can enjoy drinking alcohol-free, fruity beer that actually has great health characteristics. Although the positive sides of the beverage exist, it will be a bit harder to convince customers that functional beer is not just regular beer. However, with different promotion activities that can also change—for example, direct promotion—business subjects can gain better, stronger and more reliable relationships than from indirect promotion.

Today, because of the remarkable development of social media, there are quite a number of influencers who promote healthy lifestyles and self-awareness. Keeping that in mind, representing functional beer to millions of consumers through influencers on social media has a bright future. This may be, in some cases, expensive promotion, but this is one of the ways to reach one's desired group of consumers on a larger scale.

3. Research Interests and Production of Functional Beer

The increased recognition of healthier, organic and traditional foods and beverages is a well-established trend in today's society. The return towards simple and traditional foods often results in innovative products that are a combination of beneficial and new compounds united in one health-promoting functional food. Beer is a worldwide familiar beverage, and the addition (herbs, fungi, probiotics, etc.) or removal (alcohol, gluten, or carbohydrates) of certain compounds from it can result in a desired, almost tailored beverage for everyone to enjoy. Some of the functional additions to beers have already entered production, but some, however, are still a subject of different research.

3.1. Botanicals

The addition of different herbs and adjuncts to beer is a well-known procedure and has been used since the (presumably) middle ages and served to enhance the taste and smell.

Plants—many plants and plant extracts—were traditionally used in brewing. *Artemisia vulgaris*, *Juniperus communis*, *Melissa officinalis*, *Mentha spiata*, *Origanum vulgare*, *Pimpinella anisum*, *Rosmarinus officinalis*, *Thymus serpyllum*, *Acorus calamus*, *Cinnamomum verum*, *Hypericum perforatum*, *Lupuli strobuli*, *Urticae radix*, *Brassica nigra* and *Coriandrum sativum* are some of the plants or plant extracts that have been used in brewing and numerous studies to date [6]. As reported by Đorđević et al. [6], the addition of medicinal or aromatic herbs or their extracts to beers can result in a pleasantly flavored beverage. In sensory terms, the best rated beer was the one with lemon balm extract, and considering the functionality of the product, the best beer was the one with a thyme extract (highest content of total phenols and antioxidant activity). Belščak-Cvitanović et al. [7] investigated the addition of encapsulated green tea extracts and dry green tea extracts into Pilsner and lemon radler. For all beers with extract addition, the total phenolic content was higher at the end of storage. Industrial radler beer with green tea microbeads was rated as the best considering sensory analysis, as it was the least bitter and had a stronger and pleasant herbal taste.

Fruits—lemon juice, raspberry syrup, orange juice and grapes—are very popular as additions to the beer, which broaden the consumer population to women and people who dislike the original bitterness of beer.

For now, very promising research regarding fruit additions to beer concerns grapes. Grapes are one addition that combines the different bioactive compounds originating from beer and wine, such as phenolic compounds and anthocyanins. Several papers combining beer and wine have been published [8,9]. A special type of beer was produced by fermenting wort combined with different ratios of must (Prokupac and Muskat Hamburg). The obtained products had very specific sensory characteristics including bitterness, astringency and freshness. Although the beer samples did not show a significant statistical difference, a beer with a higher content of Muscat Hamburg was recognized as more desirable. Total phenolic compound analysis showed a higher phenolic content in the sample produced with Muskat Hamburg. These results showed that it is possible to obtain a product with pleasing sensory characteristics and enhanced functionality [8]. In 2016, Veljović [9] published research results where a special type of beer from wort and grape must (three grape varieties: Prokupac, Cabernet sauvignon and Pinot noir) was produced. *Saccharomyces cerevisiae* and *S. pastorianus* were employed for fermentation. *S. pastorianus* showed more efficiency in metabolizing wort with the addition of grape must than *S. cerevisiae.* Beers with the addition of must contained up to seven-fold more phenolic compounds than the control pilsner beer. Beers with 20% *w*/*w* of grape must added to wort showed better sensory properties. The consumption of such beer acted favorably on heartrate and blood pressure, keeping them within normal readings. Although somewhat more expensive in production, beers with the addition of grape must could be of interest, especially to craft brewers who seek diversity and functionality.

Xanthohumol (XH) is a chemical compound originating from hops. Xanthohumol is a prenylated chalcone [10]. Xanthohumol and its isomerized form isoxanthohumol display health beneficiary properties. During wort boiling and in large quantities, xanthohumol gets transformed into isoxanthohumol. Losses continue during fermentation, filtration and beer stabilization [11]. Xanthohumol can be found in hops and hop products (pellets, CO_2 extracts and ethanol extracts), and in xanthohumol-enriched hop products. In countries in which the Bavarian Purity Law is not applied [12], beer can be enriched with xanthohumol via different products. Despite the Bavarian Purity Law, the first xanthohumol-enriched beer was produced in Munich, Germany, in 2001 and was named XAN™ wheat beer. This beer was brewed in a special manner, starting with higher original wort gravity. Late hop addition in large quantities and the addition of cold brewing water in order to cool the wort down to 80 °C as fast as possible was applied in order to prevent the isomerization of xanthohumol, which resulted in >10 mg of xanthohumol/L in the finished beer [13]. The addition of xanthohumol-enriched hop products to Pilsner and stout/porter beer was conducted by Biendl et al. [14] with final concentrations of 8.1 mg/L of isoxanthohumol and <0.1 mg/L of xanthohumol in Pilsner beer and 9.0 mg/L of isoxanthohumol and 3.3 mg/L of xanthohumol in stout beer. This considerably higher content of xanthohumol in stout beer was achieved due to the partial prevention of xanthohumol isomerization by the ingredients used in the brewing of this type of beer (roasted barley, chocolate malt, etc.). Similar research was conducted by Magalhães et al. [11] and Karabin et al. [15] where they produced dark beer enriched with xanthohumol. Recent studies showed that XH displays cancer chemopreventive activities and antimutagenic and anticarcinogenic properties, with an exceptionally broad spectrum of inhibitory mechanisms at all three stages of carcinogenesis— initiation, promotion and progression [16,17]. Xanthohumol also shows a strong antioxidative effect on hydroxyl and peroxyl radicals [13].

3.2. Microorganisms

Microorganisms are an essential part of beer brewing, especially yeasts. Fermentation can be conducted using two basic types of yeast: *Saccharomyces carlsbergensis* (bottom fermenting) and *Saccharomyces cerevisiae* (top fermenting) [18].

Kefir is a traditional fermented beverage originating from the Caucasian regions. Kefir grains are comprised of various microorganisms such as bacteria (*Lactobacillus, Leuconostoc*, *Lactococcus* and *Acetobacter*), yeasts (*Kluyveromyces*, *Candida*, *Saccharomyces*, *Torulaspora*, *Kazachstania*, *Lachancea* and *Yarrowia*) and filamentous fungi, cohabiting in a natural polysaccharide kefiran and protein matrix [19–22]. It has been reported that its probiotic and prebiotic content [23] can be beneficial for human health. Kefir and its related product—kefiran—can have anti-inflammatory, antimicrobial, anti-neoplasic and antioxidant activities [24,25]. Rodrigues et al. [26] reported the production of beer with kefir and control beer with added kefiran (fermented with *Saccharomyces cerevisiae*), which resulted in increased values of phenolic content in the drink. The increased health-beneficiary synergistic effect between kefir and beer should be further investigated in relation to the potential health-promoting activities of probiotic beers. Other similar symbiotic communities of bacteria and yeasts (kombucha, boza, koumiss and borde drinks) could also be investigated and developed as health-beneficiary, functional beverages [27]. Kefir is an affordable microorganism colony and easy to culture and maintain, with a high growth rate and biomass yield, which makes it extremely favorable for industrial production. Mikyška et al. [28] investigated the production of beer-based fermented beverages using kefir grains. Worts produced from different cereals (winter wheat, oats, barley and combinations of stated cereals) were subjected to fermentation using the yeast strains RIBM163 and RIBM 164 (*Saccharomyces cerevisiae*) and/or the lactic acid bacteria RIBM2-107 and RIBM 2-108 (*Lactobacillus casei* subsp. *paracasei*) isolated from kefir grains. All the cereals and their mixtures showed satisfactory results in the sensory analysis of the produced beers/beverages and were described as pleasant and/or fruity. Citrus winter wheat malt appeared as very promising for a number of beverages with acceptable sensory properties, and non-hopped low-alcohol beverages with a fresh citrus aroma and acidic flavor are a result of fermentation using a mixed yeast and bacterial culture (RIBM 2-107 + RIBM163). The mixture of barley malt and citrus malt resulted in a light and refreshing aroma and flavor of low-alcohol beer. Low-alcohol beer produced from a mixture of oats and barley malt and fermented by the yeast strain RIBM164 is characterized as pleasant, with a fruity aroma and strong oaty notes.

Probiotics are preparations of microbial cells or components of microbial cells that act beneficially on the health of the host [29]. The four most popular probiotics—*Lactobacillus acidophilus*, *Bifidobacterium lactis* [30], *L. rhamnosus* [31] and *Lactobacillus paracasei* L26 [32]—have been investigated as possible additions in beer. Since beer contains a certain amount of alcohol (commonly 3–5%), this makes it very hard for lactic acid bacteria to survive and grow in such a medium. Sohrabvandi et al. [30] reported that beer is not an adequate medium for *Lactobacillus acidophilus* or *Bifidobacterium lactis* growth. Encapsulated *L. rhamnosus* cells showed better resistance against alcohol inhibition and were able to survive in an alcoholic environment such as beer. *Lactobacillus paracasei* L26, however, showed promising results, suggesting that beer could be a good vector for probiotic bacteria. *Saccharomyces cerevisiae* var. *bulardii* is a probiotic yeast strain recently introduced to brewing [33].

Ganoderma lucidum is a medicinal mushroom that has been used in much research regarding food functionality. According to Zhou et al. [34], *Ganoderma* has many bioactive components but the most important ones are polysaccharides, triterpenoids, low-molecular-weight proteins, sterols, ganoderic acids, unsaturated fatty acids, vitamins and minerals. Although it is praised for its anticancerogenic, antioxidative, immunomodulating and antitumor effects [35,36], its popularity for pairing with beer comes from the fact that it has a bitter taste. To combine it with beer, Leskošek-Ćukalović et al. [37,38] added alcohol extracts of *Ganoderma* to commercial beers in recommended daily doses (0.1–1.5 mL/L) in order to obtain sensorially acceptable and functional beer. Similarly, Belščak-Cvitanović et al. [7] used extracts and microencapsulated polyphenolic compounds from *Ganoderma*, which were then added to Pilsner beer, resulting in positive sensory evaluation. This kind of beer was evaluated as pleasantly bitter. Despotović [39] used finely chopped or milled mushroom to produce the extracts, and the dry mushroom body was also added to the beer. The ensory evaluation was successful, and the bitterness, which originates from triterpenes, was again rated as pleasant. These research results also pointed to the fact that the analyzed extracts can be an important source of natural antioxidants and have potential medical significance.

3.3. Elements

Selenium is a trace element that is very important for human health, and its deficiency can cause serious immune deficiency, cognitive decline and even mortality [40,41]. According to Agate et al. [42,43], beer is an especially desirable medium for selenium enrichment because yeast (*Saccharomyces cerevisiae*) is known to conduct the biotransformation of inorganic Se to bioactive and more easily absorbable organic Se compounds. Barley enrichment with Se in the field gave satisfactory results [44–46], but biofortification during malting showed equally good results.

Gold flakes can be added to beer. According to an internet source [47], they neutralizes the influence of stressed body cells that obtain strong positive charges, and by absorbing a small amount of gold, the cells would obtain and emit negative ions, making the body feel better. However, there is no scientific literature related to this topic, so the gold flakes are probably just a luxury stamp on a beer.

3.4. Low-Alcohol and Alcohol-Free Beer

Is one of the most popular functional beers available on the market. Depending on the countries' laws and the producers' equipment, alcohol-free beers can contain 0–0.5% of ethanol [48]. Low-alcohol and non-alcoholic beers are taking over the market, and it has been reported that the average sales in Europe climbed by 50% in the last 15 years [49]. Brányik et al. [49] described several methods that can be employed in order to produce alcohol-free beer: 1. removal methods (thermal-vacuum rectification and thin-film evaporators); 2. membrane processes (dialysis and reverse osmosis); 3. restricted ethanol formation during brewing (adjusted mashing process, arrested or limited fermentation process, or the use of special yeast and continuous fermentation). Each of these methods for alcohol-free beer production has certain effects on the sensory properties of the final product in comparison to the alcoholic version. One of the downsides is the flavor impairments that occur during processing: membrane processes usually result in less body and a low aromatic profile, thermal dealcoholization leads to heat-induced deterioration of the aroma profile, and beers produced using restricted ethanol formation during brewing commonly display a sweet and worty off-flavor due to the absence of alcohol and higher levels of mono- and disaccharides [50,51]. Namely, ethanol affects the retention of aldehyde in the beer, and this results in a lower perception of the worty character. It is very hard to produce low-alcohol beer with similar volatile distribution and balance as in regular beer. Flavor balance may be achieved by process adjustments as well as by adding flavor-active compounds into the final product [52,53]. Thermal processes have the tendency to increase, while the membrane processes decrease, the color of the low-alcohol beer, while the bitterness, volatile content and foam stability are commonly impaired regardless of which dealcoholization processes is applied [49]. For that reason, different post-treatment and blending techniques are applied in order to improve the sensorial quality and colloidal stability of low-alcohol beers: the addition of fresh yeast followed by maturation or by blending with the original beer [54,55], aromatic beer (beer fermented at elevated temperatures), or krausen [56]. The Barrell patent [57] suggests gently dealcoholizing beer by treating it with CO_2 from fermenting green beer and, at the end, adding krausen, followed by a maturation and filtration process [58], in order to return the higher alcohols and esters originally present in the alcoholic beer [56]. To achieve the desired properties similar to those of alcoholic beers, some additives can be added to the brew. Frequently used additives are saccharin (sweetener E954), ascorbic acid (antioxidant E300) and lactic acid (preservative E270). Saccharin is a sweetener with an unpleasant bitter or metallic aftertaste when applied in higher concentrations, but it can effectively strengthen the body of the alcohol-free beer, and dextrins can improve the flavor profile because they act retentively on the flavor-active compounds [59].

3.5. Gluten-Free Beer

Gluten is a protein fraction found in some cereals such as barley and wheat. Despite the higher prices, today's health trends—but also the growing rate of people intolerant to gluten—are responsible for the expansion of the gluten-free beer market. Although the brewing process ensures the removal of different protein fractions (some are precipitated during the primary and secondary fermentation and some get removed during colloidal stabilization and filtration) [60], gluten-free beer can be produced from different cereals such as rice, buckwheat, oats, rye, maize, sorghum or millet, which can be used both un-malted and malted [61–65].

Zarnakow et al. [66–69] considered the possibility of the use of pseudocereals: quinoa and amaranth. This resulted in several published papers in which it was reported that when using quinoa in the malting process, a malt of acceptable quality can be obtained, but amaranth did not show promising malt quality values. Dostalek et al. [60] analyzed the gluten content of many different commercially available malt types and reported that the level of gluten varied significantly between the different samples, from 19,000 ppm for Pilsner barley malt to 45,000 ppm in Carafa barley malt. Choosing the proper traditional raw material can also result in low gluten content in the final beer. Gluten-free beer does have different sensory and quality parameters in comparison to standard barley beer [70]. According to the Codex Alimentarius and the EU regulation 41/2009 [71] for gluten-free foods, beers with less than 20 mg/kg of gluten are regarded as gluten-free beers [72].

Rice (*Oryza sativa*) is a cheap nutrient source whose proteins are not considered as coeliac toxic; it consists of about 80% starch, which makes it appropriate for malting and brewing. Ceppi and Brenna [73,74] investigated different rice varieties for their suitability for producing rice malt. This resulted in the knowledge that good rice malt could be obtained, but compared to barley malt, rice malts were poorly modified during extraction. For a beer-like beverage with all-rice malt, incomplete saccharification and a more difficult filtration process were reported. The final gravity and alcohol content were satisfactory. Zutho is a traditional rice alcoholic beverage. The fruity aroma and sour taste make it very popular in India. It usually contains cca 5.0% (*v*/*v*) of alcohol and is most similar to Japanese sake [75].

Waxy varieties of sorghum (*Sorghum bicolor*) are suitable for industrial brewing. These kinds of sorghum are susceptible to hydrolysis by amylolytic and proteolytic enzymes [76–78], which makes them suitable for brewing. Sorghum beer is traditionally produced in Africa using *Saccharomyces cerevisiae* and *Lactobacillus* cultures [79]. When compared to conventional beer, sorghum beer is a viscous beverage, slightly sweet, but it can also be a little sour because of the lactic acid. The color can vary, from yellowish (sorghum malt and millet) to pinkish (sorghum malt and maize) [80].

Maize (*Zea mays*) is already well integrated into the brewing process alongside other cereals (sorghum, wheat or barley malt), since its suitability for brewing as a malted grain is poor, and therefore, it is mainly used as an adjunct. However, Zweytik and Berghofer [80] produced maize malt in order to brew bottom-fermented beer. The final beer was clear and light yellow in color, with good foam stability and a similar taste to conventional beer [80]. The relatively low price of maize and rice, and good colloidal stability properties in comparison to those of the other gluten-free commodities make them approachable for use in brewing.

Malting and brewing with pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*) is still at the experimental stage [81]. Nzelibe and Nwasike [82] compared the malting and brewing characteristics of two millet varieties (*Pennisetum typhoides* and *Digitaria exilis*). All three malts produced worts suitable for conventional brewing. Zarnkow et al. [83] optimized the malting conditions for millet, and in 2007, Zarnkow et al. [67] optimized the mashing procedure for 100% malted millet. Zarnkow et al. [84] employed top-fermenting yeasts for the production of beer from millet malt.

Teff (*Eragrostis tef*) is a small-seeded tropical grain. It also belongs to the millet group and, in Ethiopia, is used for the production of a local beer called Shamit [85].

Regarding oats (*Avena sativa* L.), the brewing industry shows an increased interest for the use of unmalted oats or oat malt because oats' proteins are tolerated by most people suffering from celiac disease. Oat beer has a peculiar character interesting for new customers [86,87]; however, an astringent and bitter taste can be a result. Klose et al. [86] brewed 100% oat malt beer; this resulted in certain downsides among which lower alcohol content than in barley beers was one. However, in the end, the 100% oat malt beers were comparable to barley malt beers. A strong berry flavor and a better reaction toward staling were also noted for oat beer.

Buckwheat (*Fagopyrum esculentum* Moench) is a pseudocereal [88] whose malt can be used for the production of malt beverages [89] and beers with reduced gluten content [90]. Due to the polyphenolic content, buckwheat malt displays high antioxidative activity [91], which makes it a very interesting raw material for functional beer. NicPhiarais et al. [92,93] reported that the use of commercial enzymes could help to improve the production of wort from 100% buckwheat. In 2010, they [93] brewed top-fermented beer from 100% buckwheat malt, and the resulting beer was comparable to wheat beer regarding the total alcohol content. Sensory analyses indicated that these buckwheat beers were acceptable regarding odor, purity of taste, mouthfeel, tingling and bitterness. A patent [94] describes the process of gluten-free beer production resulting in organoleptic properties similar to those of beer made from barley.

Amaranth (*Amaranthus* sp.) is also a pseudocereal with very small seeds and low amylase content. Beer from 100% amaranth malt had an intense bitter taste [80]. In a study conducted in 2011 by De Meo et al. [95], amaranth, however, showed improved malting properties.

Quinoa (*Chenopodium quinoa*) has been recognized as an extremely nutritious grain, displaying good-quality and high-quantity protein content and essential fatty acids [67]. Some [96] authors, in order to optimize the malting process, have investigated the influence of the steeping degree and germination time on quinoa malt quality. The produced quinoa malt beer [97] was an opaque yellow product with acceptable foam and taste. Although quinoa also has a high share of sugars, which makes it suitable for the production of malt-based beverages [98], the very small grains and significantly lower enzyme activity, in comparison to wheat or barley, limit its application in brewing.

Chestnuts (*Castanea sativa*) are gluten-free and considered to be the best substitute for barley malt regarding sensorial characteristics [99]. The starch content in chestnuts is similar to that of barley malt, but the protein share does not exceed 6% of dry weight, with the absence of a hordein fraction, which can be found abundantly in barley and barley malt [100]. Chestnuts as an adjunct to beer are, therefore, safe in terms of consumption by consumers sensitive to hordein (e.g., celiac disease or gluten intolerant consumers). The results presented in the preliminary study conducted by Velić et al. [99] indicate that chestnuts could be used in beer production as a raw material for low-gluten or gluten-free beers. Nevertheless, economic efficiency should be taken into account, since roasted chestnut grist can sometimes be much more expensive than malt.

A short overview of other methods for the cereal-free production of gluten-free beer is given in Table 1. Ensuring the removal of toxic proteins from beer can be done in several other ways [101]. This includes the use of different methods: protein precipitation with different precipitants such as tannins, silica gel and PVPP (polyvinylpolypyrrolidone); enzymatic treatments with prolyl-endopeptidase originating from *Aspergillus* spp.; and beer production without using grains, utilizing commodities such as fermented sugar syrups, molasses, enzyme-hydrolyzed maltose syrup or honey as a source of sugars. Yeast extract, hop materials, caramel, and protein from peas, soybeans, corn, rice and sorghum are added as sources of proteins, flavor and color. Raw material selection purports the use of a patented method of suppressing the hordein production in germinating and reproductive barley in the field.

Table 1. Other methods for production of gluten-free beer.

Method		Source
Protein precipitation	Tannins	[102]
	Silica gel	[61]
	PVPP *	[103]
Enzymatic treatment	Prolyl-endopeptidase	[102,104]
Sans grain production	Fermentable sugars	[105]
	Yeast extract	[106]
	Non-cereal protein	[107]
Raw material	Suppression of hordein production	[108]

* polyvinylpolypyrrolidone.

3.6. Healthier Beer

Beer with L-*carnitine* addition has acceptable sensory properties and is described as pleasant. Besides the pleasant taste, it has been shown to increase human fat metabolism and lipolysis capacity [109].

In terms of *estrogenic beer*, prenylnaringenin is known as one of the most potent phytoestrogens originating from hops [110], which, due to its low concentration in beer (<100 µg/L), appeared to be insignificant for any health benefits. However, Possemiers et al. [110] reported that isoxanthohumol can be transformed into 8-pre-nylnaringenin by the indigenous human intestinal microbiome. The concentration of isoxanthohumol can commonly reach 1–2 µg/mL, so it is obvious that the isomerization increases the total concentration of prenylnaringenin in the human body [111]. According to Stevens and Page (2004) [10], 8-prenylnaringenin acts as a prospective estrogen and can be applied for the therapy and prevention of postmenopausal problems such as hot flashes.

Spirulina beer is alga rich, with bioactive components. It has the ability to reduce oxidant stress and boost the immune system, so it can match the nutritional components and flavor of traditional beer but also add nutritional value for the consumer [112].

Oats are rich in β-glucan, and a special method has been developed in order to produce oat beer rich in β-glucan [113].

Extremely demanded by the consumers, low-carbohydrate beers have been an even better selling beverage than regular beers. Light beers are a result of a highly fermentable wort, enzymatic degradation and the addition of adjuncts. The lower the dextrin content in the final beer, the lower the calorie count will be [113].

4. Consumers' Acceptance and Prospects

Although beer by itself is a nutritious (Table 2) and refreshing beverage, rich in different minerals and vitamins, today's research is focused on improving the functionality of different beers and beer-based beverages.

Table 2. The average levels of nutritive components in beer.

Component	Unit Per L	Value	Source
Protein	g	0.2–6.6	[114]
Thiamine	mg	<0.08	[112]
Riboflavin	mg	<0.8	[112]
Niacin	mg	3–8	[112]
Vitamin B6	mg	<1.7	[112]
Folate	μg	40–600	[112]
Vitamin B12	μg	3–30	[112]
Biotin	μg	2–15	[112]
Phosphate	mg	260–995	[112]
Potassium	mg	200–600	[112]
Chloride	mg	150–400	[112]
Sulphate	mg	60–300	[112]
Calcium	mg	20–160	[112]
Silica	mg	40–120	[112]
Sodium	mg	10–100	[112]
Magnesium	mg	60–250	[112]
Zinc	mg	0.02–4.5	[112]
Copper	mg	0.02–0.4	[112]
Iron	mg	0.01–0.3	[112]
Manganese	mg	0.03–0.2	[112]
Fluoride	mg	0.09–0.2	[112]
Cobalt	mg	0.01–0.1	[112]
Lead	mg	<0.1	[112]
Selenium	mg	<0.007	[112]
Polyphenols	mg	32–426	[115,116]
Melanoidins	g	0.6–1.5	[117]
Ethanol	% (*v*/*v*)	3–9	[118]
Energy	kcal	150–1100	[112]

According to the Internet, some of the USA brewing industries are starting to produce beer with bee pollen, blackcurrant and salt; coriander and Himalayan salt are being added to ale in order to make it more functional for runners. European breweries are also turning toward more functional beers, so they remain focused on non-alcoholic or low-alcohol beers with lower numbers of calories [4,119]. The increase in demand for functional beers is encouraging innovation and research in that field, and the future looks bright for health-boosting beers or beer-based beverages.

The increasing demand for functional beers is promising and implies that the sensory characteristics are alluring to the consumers. The sensory acceptance of functional beers is evaluated according to several basic parameters such as aroma, taste, body, bitterness, liveliness and overall impression [37]. Several studies dealing with the sensory acceptance of different functional beers have been published [6,7,28,37,39]. Generally, formulations had to be adjusted in order for them to display acceptable sensory properties. Mikyška et al. [28] researched beer/low-alcohol beer produced from a mixture of oats and barley malt fermented by the yeast strain RIBM164. The sensory results described it as a pleasant drink with a fruity aroma and pleasantly strong grainy notes. A similar situation was obtained when investigating the addition of *Ganoderma lucidum* to beer; this type of beer was sensorially acceptable and rated as pleasantly bitter. In research conducted by Despotović [39], the best sensory properties were attributed to extracts made of finely chopped mushroom bodies extracted with 40% (*v*/*v*) ethanol without ultrasound treatment.

Antioxidative activity was also measured in several studies mentioned in this paper. Namely, the addition of different extracts of plants increases the polyphenolic content and antioxidative activity of formulated beers. Đorđević et al. [6] conducted research with adding different plant extracts to beer, and the best sensory properties were attributed to a beer with a lemon balm extract, while a beer with a thyme extract was revealed as the most functional, considering the content of total phenols and antioxidant activity. Veljović [8] added grape must to beer, and the results showed that beers with the addition of must contained seven-fold higher levels of phenolic compounds than control beers. Subsequently, higher antioxidant capacity was also noted in beers with the addition of grape must than in control Pilsner beers.

5. Conclusions

Functional beer expansion will probably continue to grow. New additions, adjuncts, aromas and tastes will continue to attract different types of people with different preferences, medical conditions or religious views. The propagation of functional beers will probably establish a new type of health-conscious customer who likes to enjoy traditional beer with a twist. The possibilities are endless when it comes to combining beer with different beverages, herbs, spices and other functional compounds. However, due to the elevated production price, the final product will surely be more expensive than regularly available beers such as lagers or Pilsner-style beers.

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References

1. Sanguansri, L.; Augustin, M.A. Microencapsulation in functional food product development. In *Functional Food Product Development*; Smith, J., Charter, E., Eds.; John Wiley & Sons: Oxford, UK, 2010; pp. 3–23.
2. Wootton-Beard, P.C.; Ryan, L. Improving public health—The role of antioxidant-rich fruit and vegetable beverages. *Food Res. Int.* **2011**, *44*, 3135–3148. [CrossRef]
3. Kausar, H.; Saeed, S.; Ahmad, M.M.; Salam, A. Studies on the development and storage stability of cucumber-melon functional drink. *J. Agric. Res.* **2012**, *50*, 239–248.
4. Gould, K. 'Functional Beverages' are the Trend that Everyone's Going to Be Talking About. Available online: https://www.forbes.com/sites/kennygould/2019/04/28/functional-beverage-beer/#7c43dd553910 (accessed on 2 March 2020).
5. Available online: https://www.stealingshare.com/pages/beer-marketing/ (accessed on 5 May 2020).
6. Đorđević, S.; Popović, D.; Despotović, S.; Veljović, M.; Atanacković, M.; Cvejić, J.; Nedović, V.; Leskošek-Čukalović, I. Extracts of medicinal plants as functional beer additives. *Chem. Ind. Chem. Eng. Q.* **2016**, *22*, 301–308.
7. Belščak-Cvitanović, A.; Nedović, V.; Salević, A.; Despotović, S.; Komes, D.; Nikšić, M.; Bugarski, B.; Leskošek-Ćukalović, I. Modification of functional quality of beer by using microencapsulated green tea (*Camellia sinensis* L.) and Ganoderma mushroom (*Ganoderma lucidum* L.) bioactive compounds. *Chem. Ind. Chem. Eng. Q.* **2017**, *23*, 457–471. [CrossRef]
8. Veljović, M. Chemical, Functional and Sensory Properties of Beer Enriched with Biologically Active Compounds of Grape. Ph.D. Thesis, Faculty of Agriculture, University of Belgrade, Beograd, Serbia, 2016.
9. Veljović, M.; Đorđević, R.; Leskošek-Čukalović, I.; Lakić, N.; Despotović, S.; Pecić, S.; Nedović, V. The possibility of producing a special type of beer made from wort with the addition of grape must. *J. Inst. Brew.* **2010**, *116*, 440–444. [CrossRef]
10. Stevens, J.F.; Page, J.E. Xanthohumol and related prenylflavonoids from hops and beer: To your good health! *Phytochemistry* **2004**, *65*, 1317–1330. [CrossRef]
11. Magalhães, P.J.; Dostalek, P.; Cruz, J.M.; Guido, L.F.; Barros, A.A. The impact of a xanthohumol-enriched hop product on the behavior of xanthohumol and isoxanthohumol in pale and dark beers: A pilot scale approach. *J. Inst. Brew.* **2008**, *114*, 246–256. [CrossRef]
12. Krottenthaler, M. Hops. In *Handbook of Brewing Processes, Technology, Markets*; Eßlinger, H.M., Ed.; Wiley-VCH Verlag GmbH and Co.: Weinheim, Germany, 2009; pp. 85–104.

13. Burberg, F.; Zarnkow, M. Special production methods. In *Handbook of Brewing: Processes, Technology, Markets*; Eβlinger, H.M., Ed.; Wiley-VCH Verlag GmbH and Co.: Weinheim, Germany, 2009; pp. 235–256.
14. Biendl, M.; Methner, F.J.; Stettner, G.; Walker, C.J. Brewing trials with a xanthohumol enriched hop product. *Brauwelt Int.* **2004**, *22*, 182–184.
15. Karabin, M.; Jelinek, L.; Kincl, T.; Hudcova, T.; Kotlikova, B.; Dostalek, P. New approach to the production of xanthohumol-enriched beers. *J. Inst. Brew.* **2013**, *119*, 98–102. [CrossRef]
16. Gerhäuser, C. Beerconstituents as potential cancer chemopreventive agents. *Europ. J. Cancer* **2005**, *41*, 1941–1954. [CrossRef]
17. Ferk, F.; Huber, W.; Filipič, M.; Bichler, J.; Haslinger, E.; Mišik, M.; Nersesyan, A.; Grasl-Kraupp, B.; Žegura, B.; Knasmuller, S. Xanthohumol, a prenylated flavonoid contained in beer, prevents the induction of preneoplastic lesions and DNA damage in liver and colon induced by the heterocyclic aromatic amine amino-3-methyl-imidazo[4,5-f]quinoline (IQ). *Mutat. Res.* **2010**, *691*, 17–22. [CrossRef] [PubMed]
18. Yamagishi, H.; Ogata, T. Chromosomal structures of bottom fermenting yeasts. *Syst. Appl. Microbiol.* **1999**, *22*, 341–353. [CrossRef]
19. Farnworth, E.R. Kefir—A complex probiotic. *Food Sci. Technol. Bull. Funct.* **2005**, *2*, 1–17. [CrossRef]
20. Garofalo, C.; Osimani, A.; Milanović, V.; Aquilanti, L.; De Filippis, F.; Stellato, G.; Di Mauro, S.; Turchetti, B.; Buzzini, P.; Ercolini, D.; et al. Bacteria and yeast microbiota in milk kefir grains from different Italian regions. *Food Microbiol.* **2015**, *49*, 123–133. [CrossRef] [PubMed]
21. Jianzhong, Z.; Xiaoli, L.; Hanhu, J.; Mingsheng, D. Analysis of the microflora in Tibetan kefir grains using denaturing gradient gel electrophoresis. *Food Microbiol.* **2009**, *26*, 770–775. [CrossRef]
22. Leite, A.M.O.; Mayoa, B.; Rachid, C.T.; Peixoto, R.S.; Silva, J.T.; Paschoalin, V.M.; Delgado, S. Assessment of the microbial diversity of Brazilian kefir grains by PCR-DGGE and pyrosequencing analysis. *Food Microbiol.* **2012**, *31*, 215–221. [CrossRef]
23. Schneedorf, J.M. Kefir D'Aqua and its probiotic properties. In *Probiotic in Animals*; Rigobelo, E.C., Ed.; Intech Open: London, UK, 2012; p. 284.
24. Chen, Z.; Shi, J.; Yang, X.; Nan, B.; Liu, Y.; Wang, Z. Chemical and physical characteristics and antioxidant activities of the exopolysaccharide produced by Tibetan kefir grains during milk fermentation. *Int. Dairy J.* **2015**, *43*, 15–21. [CrossRef]
25. Rodrigues, K.L.; Caputo, L.R.G.; Carvalho, J.C.T.; Evangelista, J.; Schneedorf, J.M. Antimicrobial and healing activity of kefir and kefiran extract. *Int. J. Antimicrob. Agents* **2005**, *25*, 404–408. [CrossRef]
26. Rodrigues, K.L.; Araújo, T.H.; Schneedorf, J.M.; Ferreira, C.S.; Moraes, G.O.I.; Coimbra, R.S.; Rodrigues, M.R. A novel beer fermented by kefir enhances anti-inflammatory and anti-ulcerogenic activities found isolated in its constituents. *J. Funct. Foods* **2016**, *21*, 58–69.
27. Schneedorf, J.M. Oligosaccharides from ancient beverages fermented by symbiotic cultures. In *Oligosaccharides: Food Sources, Biological Roles and Health Implications*; Schweizer, L.S., Krebs, S.J., Eds.; NOVA Science Publishers Inc.: New York, NY, USA, 2014; pp. 287–341.
28. Mikyška, A.; Matoulková, D.; Slabý, M.; Kubizniaková, P.; Hartman, I. Characterization of the strains isolated from kefir grains and their use for the production of beer-based fermented beverages from nontraditional cereals. *Kvasny Prum.* **2015**, *61*, 10–11. [CrossRef]
29. Tamime, A.Y.; Saarela, M.; Sondergaard, A.K.; Mistry, V.V.; Shah, N.P. Production and maintenance of viability of probiotic microorganisms in dairy products. In *Probiotic Dairy Products*; Adnan, T., Ed.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2005; pp. 39–72.
30. Sobrahvandi, S.; Razavi, S.H.; Mousavi, S.M.; Mortazavian, A.M. Viability of probiotic bacteria in low alcohol- and non-alcoholic beer during refrigerated storage. *Philipp. Agric. Sci.* **2010**, *93*, 24–28.
31. Haffner, F.B.; Pasc, A. Freeze-dried alginate-silica microparticles as carriers of probiotic bacteria in apple juice and beer. *LWT—Food Sci. Technol.* **2018**, *91*, 175–179. [CrossRef]
32. Chan, M.Z.A.; Chua, J.Y.; Toh, M.; Liu, S.-Q. Survival of probiotic strain *Lactobacillus paracasei* L26 during co-fermentation with *S. cerevisiae* for the development of a novel beer beverage. *Food Microbiol.* **2019**, *82*, 541–550. [CrossRef] [PubMed]
33. Capece, A.; Romaniello, R.; Pietrafesa, A.; Siesto, G.; Pietrafesa, R.; Zambuto, M.; Romano, P. Use of *Saccharomyces* cerevisiae var. boulardii in co-ermentations with *S. cerevisiae* for the production of craft beers with potential healthy value-added. *Int. J. Food Microbiol.* **2018**, *284*, 22–30. [CrossRef] [PubMed]

34. Zhou, X.; Lin, J.; Yin, Y.; Zhao, J.; Sun, X.; Tang, K. *Ganodermataceae*: Natural products and their related pharmacological functions. *Am. J. Chin. Med.* **2007**, *35*, 559–574. [CrossRef]
35. Yuen, J.; Gohel, M. Anticancer effects of *Ganoderma lucidum*: A review of scientific evidence. *Nutr. Cancer* **2005**, *5*, 11–17. [CrossRef]
36. Gao, H.; Zhou, F. Chemopreventive and tumoricidal properties of Ling Zhi mushroom *Ganoderma lucidum* (W.Curt.: Fr.) Lloyd (Aphyllophoromycetideae). Part II. Mechanism considerations (Review). *Int. J. Med. Mushrooms* **2004**, *6*, 219–230. [CrossRef]
37. Leskošek-Ćukalović, I.; Despotović, S.; Lakić, N.; Nikšić, M.; Nedović, V.; Tešević, V. *Ganoderma lucidum*—Medical mushroom as a raw material for beer with enhanced functional properties. *Food Res. Int.* **2010**, *43*, 2262–2269. [CrossRef]
38. Leskošek-Ćukalović, I.; Despotović, S.; Nedović, V.; Lakić, N.; Nikšić, M. New type of beer—Beer with improved functionality and defined pharmacodynamic properties. *Food Technol. Biotechnol.* **2010**, *48*, 384–391.
39. Despotović, S. Biochemical and Functional Properties of Beer with the Addition of *Ganoderma lucidum*. Mushroom. Ph.D. Thesis, Faculty of Agriculture, University of Belgrade, Beograd, Serbia, 29 June 2017.
40. Rayman, M.P. Selenium and human health. *Lancet* **2012**, *379*, 1256–1268. [CrossRef]
41. Fairweather-Tait, S.J.; Bao, Y.P.; Broadley, M.R.; Collings, R.; Ford, D.; Hesketh, J.E.; Hurst, R. Selenium in human health and disease. *Antioxid. Redox Signal.* **2011**, *14*, 1337–1383. [CrossRef] [PubMed]
42. Alzate, A.; Canas, B.; Pérez-Munguía, S.; Hernández-Mendoza, H.; PérezConde, C.; Gutiérrez, A.M.; Cámara, C. Evaluation of the inorganic selenium biotransformation in selenium-enriched yogurt by HPLC-ICP-MS. *J. Agric. Food Chem.* **2007**, *55*, 9776–9783. [CrossRef] [PubMed]
43. Alzate, A.; Fernández-Fernández, A.; Pérez-Conde, C.; Gutiérrez, A.M.; Cámara, C. Comparison of biotransformation of inorganic selenium by *Lactobacillus* and *Saccharomyces* in lactic fermentation process of yogurt and kefir. *J. Agric. Food Chem.* **2008**, *56*, 8728–8736. [CrossRef] [PubMed]
44. Gibson, C.; Park, Y.H.; Myoung, K.H.; Suh, M.K.; McArthur, T.; Lyons, G.; Stewart, D. The bio-fortification of barley with selenium. In Proceedings of the Institute of Brewery & Distillating (Asia-Pacific Section) Carventron, Hobart, Tasmania, 19–24 March 2006; pp. 19–24.
45. Rodrigo, S.; Santamaria, O.; Chen, Y.; McGrath, S.P.; Poblaciones, M.J. Selenium speciation in malt, wort, and beer made from selenium-biofortified two-rowed barley grain. *J. Agric. Food Chem.* **2014**, *62*, 5948–5953. [CrossRef] [PubMed]
46. Revenco, D.; Vomáčková, M.; Jelínek, L.; Mestek, O.; Koplík, R. Selenium species in selenium-enriched malt. *Kvas. Prum.* **2019**, *65*, 134–141. [CrossRef]
47. The World's First Beer with Pure Gold Flakes Promises Good Health. Available online: https://luxurylaunches.com/other_stuff/the_worlds_first_beer_with_pure_gold_flakes_promises_good_health.php (accessed on 4 February 2020).
48. Eßlinger, H.M.; Narzis, L. Beer. In *Ullmann's Encyclopedia of Industrial Chemistry*, 5th ed.; Chadwick, S.S., Ed.; MCB UP Ltd.: Bingley, UK, 1988; Volume 16, pp. 177–221.
49. Brányik, T.; Silva, D.P.; Baszczyňski, M.; Lehnert, R.; E Silva, J.B.A. A review of methods of low alcohol and alcohol-free beer production. *J. Food Eng.* **2012**, *108*, 493–506. [CrossRef]
50. Montanari, L.; Marconi, O.; Mayer, H.; Fantozzi, P. Production of alcohol-free beer. In *Beer in Health and Disease Prevention*; Preedy, V.R., Ed.; Elsevier Inc.: Burlington, MA, USA, 2009; pp. 61–75.
51. Perpète, P.; Collin, S. Influence of beer ethanol content on the wort flavor perception. *Food Chem.* **2000**, *71*, 379–385. [CrossRef]
52. Daenen, L.; Saison, D.; De Schutter, D.P.; De Cooman, L.; Verstrepen, K.J.; Delvaux, F.R.; Derdelinckx, G.; Verachtert, H. Bioflavoring of beer through fermentation, refermentation and plant parts addition. In *Beer in Health and Disease Prevention*; Preedy, V.R., Ed.; Elsevier Inc.: Burlington, MA, USA, 2009; pp. 33–49.
53. Heymann, H.; Goldberg, J.R.; Wallin, C.E.; Bamforth, C.W. A "beer" made from a bland alcohol base. *J. Am. Soc. Brew. Chem.* **2010**, *68*, 75–76. [CrossRef]
54. Schedl, S.; Eppinger, H.; Schuler, V. Process for the Production of Alcohol-Free Yeast White Beer. U.S. Patent 4790,993, 27 October 1989.
55. Da Silva, P.M.; De Wit, B. Spinning cone column distillation—Innovative technology for beer dealcoholisation. *Cerevisia* **2008**, *33*, 91–95.
56. Narziss, L.; Back, W.; Liebhard, M. Optimization of biological process for the production of alcohol free beer using suitable cultures. *Brauwelt Int.* **1991**, *1*, 52–57.

57. Barrell, G.W. Process for the Production of Fermented Beverages. G.B. Patent 2033,424, 1980.
58. Zürcher, A.; Jakob, M.; Back, W. Improvements in flavor and colloidal stability of alcohol free beers. In Proceedings of the European Brewing Convention Congress, Prague, Czech Republic, 14–19 May 2005.
59. Louant, G.; Dufour, J.-P. Effect of dextrins composition on flavor characteristics. In Proceedings of the European Brewing Convention Congress, Lisbon, Portugal; 1991.
60. Dostálek, P.; Hochel, I.; Méndez, E.; Hernando, A.; Gabrovská, D. Immunochemical determination of gluten in malts and beers. *Food Addit. Contam.* **2006**, *23*, 1074–1078. [CrossRef] [PubMed]
61. Schnitzenbaumer, B.; Kerpes, R.; Titze, J.; Jacob, F.; Arendt, E.K. Impact of various levels of unmalted oats (*Avena sativa* L.) on the quality and processability of mashes, worts, and beers. *J. Am. Soc. Brew. Chem.* **2012**, *70*, 142–149. [CrossRef]
62. Hübner, F.; Schehl, B.D.; Thiele, F.; Arendt, E.K. Investigation of the malting behavior of oats for brewing purposes. *J. Am. Soc. Brew. Chem.* **2009**, *67*, 235–241. [CrossRef]
63. Hanke, S.; Zarnkow, M.; Kreisz, S.; Back, W. Hafer in der Malz und Bierbereitung (Oat in malting and brewing). *Brauwelt* **2005**, *8–9*, 216–219.
64. Adetunji, A.I.; Khoza, S.; de Kock, H.L.; Taylor, J.R.N. Influence of sorghum grain type on wort physico-chemical and sensory quality in a whole-grain and commercial enzyme mashing process. *J. Inst. Brew.* **2013**, *119*, 156–163. [CrossRef]
65. Agu, R.C.; Goodfellow, V.; Bryce, J.H. Effect of Mashing Regime on fermentability of malted sorghum. *Tech. Q. Master Brew. Assoc. Am.* **2011**, *48*, 60–66. [CrossRef]
66. Zarnkow, M.; Kreisz, S. Beer and innovative drinks based on malted cereals and pseudo-cereals. In Proceedings of the ICC Jubilee Conference, Vienna, Austria, 3–6 July 2005.
67. Zarnkow, M.; Geyer, T.; Lindemann, B.; Burberg, F.; Back, W.; Arendt, E.K.; Kreisz, S. The use of response surface methodology to optimise malting conditions of quinoa (*Chenopodium quinoa* L.) as raw material for gluten-free food and beverages. *Brew. Sci.* **2007**, *60*, 118–126.
68. Zarnkow, M.; Geyer, T.; Lindemann, B.; Burberg, F.; Back, W.; Arendt, E.K.; Kreisz, S.; Gastl, M. Optimization of the malting conditions of quinoa. *Brauwelt* **2008**, *148*, 374–379.
69. Zarnkow, M.; Kessler, M.; Burberg, F.; Kreisz, S.; Back, W. Gluten free beer from malted cereals and pseudocereals. In Proceedings of the European Brewing Convention Congress, Prague, Czech Republic, 14–19 May 2005; Fachverlag Hans Carl: Nűrnberg, Germany, 2005; pp. 104/1–104/8.
70. Kerpes, R.; Fischer, S.; Becker, T. The production of gluten-free beer: Degradation of hordeins during malting and brewing and the application of modern process technology focusing on endogenous malt peptidases. *Trends Food Sci. Technol.* **2017**, *67*, 129–138. [CrossRef]
71. Codex Alimentarius Commission. Commission regulation (EC) No 41/2009 of 20 January 2009 concerning the composition and labelling of foodstuffs suitable for people intolerant to gluten. *Off. J. Eur. Union* **2009**, *21*, L16.
72. Knorr, V.; Wieser, H.; Koehler, P. Production of gluten-free beer by peptidase treatment. *Eur. Food Res. Technol.* **2016**, *242*, 1129–1140. [CrossRef]
73. Ceppi, E.L.M.; Brenna, O.V. Brewing with rice malt e a gluten-free alternative. *J. Inst. Brew.* **2010**, *116*, 275–279. [CrossRef]
74. Ceppi, E.L.M.; Brenna, O.V. Experimental studies to obtain rice malt. *J. Agric. Food Chem.* **2010**, *58*, 7701–7707. [CrossRef]
75. Teramoto, Y.; Yoshida, S.; Ueda, S. Characteristics of a rice beer (zutho) and a yeast isolated from the fermented product in Nagaland, India. *World J. Microbiol. Biotechnol.* **2002**, *18*, 813–816. [CrossRef]
76. Del Pozo-Insfran, D.; Urias-Lugo, D.; Hernandez-Brenes, C.; Saldivar, S.O.S. Effect of amyloglucosidase on wort composition and fermentable carbohydrate depletion in sorghum lager beers. *J. Inst. Brew.* **2004**, *110*, 124–132. [CrossRef]
77. Goode, D.; Halbert, C.; Arendt, E.K. Optimisation of mashing conditions when mashing with unmalted sorghum and commercial enzymes. *J. Am. Assoc. Brew. Chem.* **2003**, *61*, 69–78.
78. Obeta, J.A.N.; Okungbowa, J.; Ezeogu, L.I. Malting of sorghum: Further studies on factors influencing alpha-amylase activity. *J. Inst. Brew.* **2000**, *106*, 295–304. [CrossRef]
79. Lyumugabe, F.; Gros, J.; Nzungize, J.; Bajyana, E.; Thonart, P. Characteristics of African traditional beers brewed with sorghum malt: A review. *Biotechnol. Agron. Soc. Environ.* **2012**, *16*, 509–530.

80. Zweytik, G.; Berghofer, E. Production of gluten-free beer. In *Gluten-Free Food Science and Technology*; Gallagher, E., Ed.; Wiley-Blackwell: Oxford, UK, 2009.
81. Taylor, J.R.N.; Schober, T.J.; Bean, S.R. Novel food and non-food uses for sorghum and millets. *J. Cereal Sci.* **2006**, *44*, 252–271. [CrossRef]
82. Nzelibe, H.C.; Nwasike, C.C. The brewing potential of acha (*Digitaria exilis*) malt compared with pearl millet (*Pennisetum typhoides*) malts and sorghum (*Sorghum bicolor*) malts. *J. Inst. Brew.* **1995**, *101*, 345–350. [CrossRef]
83. Zarnkow, M.; Kessler, M.; Back, W.; Arendt, E.K.; Gastl, M. Optimisation of the mashing procedure for 100% malted proso millet (*Panicum miliaceum* L.) as a raw material for gluten-free beverages and beers. *J. Inst. Brew.* **2010**, *116*, 141–150.
84. Zarnkow, M.; Kessler, M.; Burberg, F.; Back, W.; Arendt, E.K.; Kreisz, S. The use of response surface methodology to optimise malting conditions of proso millet (*Panicum miliaceum* L.) as a raw material for gluten-free foods. *J. Inst. Brew.* **2007**, *113*, 280–292. [CrossRef]
85. Tatham, A.S.; Fido, R.J.; Moore, C.M.; Kasarda, D.D.; Kuzmicky, D.D.; Keen, J.N.; Shewry, P.R. Characterisation of the major prolamins of tef (*Eragrostis tef*) and finger millet (*Eleusine coracana*). *J. Cereal Sci.* **1996**, *24*, 65–71. [CrossRef]
86. Klose, C.; Mauch, A.; Wunderlich, S.; Thiele, F.; Zarnkow, M.; Jacob, F.; Arendt, E.K. Brewing with 100% oat malt. *J. Inst. Brew.* **2011**, *117*, 411–421.
87. Kordialik-Bogacka, E.; Bogdan, P.; Diowksz, A. Malted and unmalted oats in brewing. *J. Inst. Brew.* **2014**, *120*, 390–398. [CrossRef]
88. Janovská, D.; Káš, M. Pohanka. In *Pěstování a Využití Minoritních Obilnina Pseudoobilnin v Ekologickém Zemědělství*; Konvalina, P., Ed.; Jihočeská univerzita v Českých Budějovicích: České Budějovice, Czech Republic, 2012; pp. 101–116. ISBN 978-80-87510-24-7.
89. Prokeš, J.; Gabrovská, D.; Rysová, J.; Paulíčková, I. Nápoj s Obsahem Rutinu (Beverage Containing Rutin). Užitný Vzor (Utility Model) 19144.Praha, 8 December 2008.
90. Škach, J.; Prokeš, J.; Hašková, D. Pivo se Sníženým Obsahem Glutenu a Způsob Jeho Výroby (Beer with Reduced Gluten Content and the Method of Its Production). CZ Patent 303 804.Praha, 28 March 2013.
91. Gabrovská, D.; Ouhrabková, J.; Rysová, J.; Fiedlerová, V.; Holasová, M.; Laknerová, I.; Winterová, R.; Prokeš, J.; Hartman, I.; Vavreinová, S. Nutriční hodnocení sladů z obilovin a pseudoobilovin (Nutritional assessment of malts from cereals and pseudocereals). *Úroda Vědecká Příloha* **2011**, *12*, 133–136.
92. NicPhiarais, B.P.; Schehl, B.D.; Olivera, J.C.; Arendt, E.K. Use of response surface methodology to investigate the effectiveness of commercial enzymes on buckwheat malt for brewing purposes. *J. Inst. Brew.* **2006**, *64*, 324–332.
93. NicPhiarais, B.P.N.; Mauch, A.; Schehl, B.D.; Zarnkow, M.; Gastl, M.; Herrmann, M.; Zannini, E.; Ardent, E.K. Processing of a top fermented beer brewed from 100% buckwheat malt with sensory and analytical characterisation. *J. Inst. Brew.* **2010**, *116*, 265–274.
94. Maccagnan, G.; Pat, A.; Collavo, F.; Ragg, G.L.; Bellini, M.P. Gluten-Free Beer. European Patent Specif. EP0949329B1, 2004.
95. De Meo, B.; Freeman, G.; Marconi, O.; Booer, C.; Perretti, G.; Fantozzi, P. Behaviour of malted cereals and pseudocereals for gluten-free beer production. *J. Inst. Brew.* **2011**, *117*, 541–546. [CrossRef]
96. Wrigley, C.; Corke, H.; Walker, C.E. *Encyclopedia of Grain Science*; Elsevier Academic Press: Oxford, UK, 2004.
97. Zweytick, G.; Sauerzopf, E.; Berghofer, E. Production of gluten free beer. In Proceedings of the AACC Annual Meeting, Orlando, FL, USA, 11–14 September 2005.
98. Ogunbengle, H.N. Nutritional evaluation and functional properties of quinoa (*Chenopodium quinoa*) flour. *Int. J. Food Sci. Nutr.* **2003**, *54*, 153–158. [CrossRef] [PubMed]
99. Velić, N.; Mujić, I.; Krstanović, V.; Velić, D.; Franić, M.; Sombol, S.Z.; Mastanjević, K. Chestnut in beer production: Applicability and effect on beer quality parameters. *Acta Hortic.* **2018**, *1220*, 209–214. [CrossRef]
100. Gupta, M.; Abu-Ghannam, N.; Gallaghar, E. Barley for brewing: Characteristic changes during malting, brewing, and applications of its by-products. *Compr. Rev. Food Sci. Food Saf.* **2010**, *9*, 318–328. [CrossRef]
101. Hager, A.-S.; Taylor, J.P.; Waters, D.M.; Ardent, E.K. Gluten free beer—A review. *Trends Food Sci. Technol.* **2014**, *36*, 44–54. [CrossRef]
102. Van Landschoot, A. Gluten-free barley malt beers. *Cerevisia* **2011**, *36*, 93–97. [CrossRef]
103. Siebert, K.J.; Lynn, P.Y. Mechanisms of beer colloidal stabilization. *J. Am. Soc. Brew. Chem.* **1998**, *55*, 73–78. [CrossRef]

104. Guerdrum, L.J.; Bamforth, C.W. Prolamin levels through brewing and the impact of prolyl endoproteinase. *J. Am. Soc. Brew. Chem.* **2012**, *70*, 35–38. [CrossRef]
105. Nakatani, K. Beer in Japan—Present and future trends. *Brew. Distill. Int.* **2007**, *3*, 54–57.
106. Klisch, R.J. Gluten-Free Beer and Method for Making the Same. U.S. Patent Application 2009 0068309 A1, 12 March 2009.
107. Scott, D.R. Liquid Mixture for Producing a Substantially Gluten Free Beer in Conformity with Jewish and Orthodox Law. U.S. Patent 2005 0170042 A1, 8 April 2005.
108. Tanner, G.J.; Howitt, C.A. Barley with Low Levels of Hordeins. U.S. Patent 20110135784 A1, 6 June 2011.
109. Liangyun, S. Beer Containing L-Carnitine. CN106916676, 2017.
110. Possemiers, S.; Bolca, S.; Grootaert, C.; Heyerick, A.; Decroos, K.; Dhooge, W.; De Keukeleire, D.; Rabot, S.; Verstraete, W.; Van de Wiele, T. The prenylflavonoid isoxanthohumol from hops (*Humulus lupulus* L.) is activated into the potent phytoestrogen 8-prenylnaringenin in vitro and in the human intestine. *J. Nutr.* **2006**, *136*, 1862–1867. [CrossRef] [PubMed]
111. Possemiers, S.; Verstraete, W.; Wiele, T.-V. Estrogenicity of beer: The role of intestinal bacteria in the activation of the beer flavonoid isoxanthohumol. In *Beer in Health and Disease Prevention*; Preedy, V.R., Ed.; Elsevier: Oxford, UK, 2009; pp. 523–539.
112. Leskošek-Čukalović, I.J. Beer as an integral part of healthy diets: Current knowledge and perspective. In *Emerging and Traditional Technologies for Safe, Healthy and Quality Food*; Nedović, V., Raspor, P., Lević, J., Tumbas Šaponjac, V., Barbosa-Cánovas, G.V., Eds.; Springer: Cham, Switzerland, 2016; pp. 111–144.
113. Stewart, G.; Priest, F.G. *Handbook of Brewing*, 2nd ed.; CRC Taylor & Francis Group: Boca Raton, FL, USA, 2006.
114. Statista: Protein Content in Selected Types of Beer Worldwide 2016. Available online: https://www.statista.com/statistics/553481/protein-content-in-beer-worldwide/ (accessed on 15 March 2020).
115. Tedesco, I.; Nappo, A.; Petitto, F.; Iacomino, G.; Nazzaro, F.; Palumbo, R.; Russo, G.L. Antioxidant and cytotoxic properties of lyophilized beer extracts on HL-60 cell line. *Nutr. Cancer* **2005**, *52*, 74–83. [CrossRef] [PubMed]
116. Vinson, J.A.; Mandarano, M.; Hirst, M. Phenol antioxidant quantity and quality in foods: Beers and the effect of two types of beer on an animal model of atherosclerosis. *J. Agric. Food Chem.* **2003**, *51*, 5528–5533. [CrossRef]
117. Rivero, D.; Perez-Magarino, S.; Gonzalez-San, M.L.; Valls-Belles, V.; Codoner, P.; Muniz, P. Inhibition of induced DNA oxidative damage by beers: Correlation with the content of polyphenols and melanoidins. *J. Agric. Food Chem.* **2005**, *53*, 3637–3642. [CrossRef]
118. Rajendram, R.; Preedy, R.V. Ethanol in beer: Production, absorption and metabolism. In *Beer in Health and Disease Prevention*; Preedy, V.R., Ed.; Elsevier Inc.: Burlington, MA, USA, 2009; pp. 431–440.
119. Anzilotti, E. Why 'Performance Beer' is The Newest Trend in Sports Beverages. Available online: https://www.fastcompany.com/90372213/why-performance-beer-is-the-newest-trend-in-sports-beverages (accessed on 15 May 2020).