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Review article

A comprehensive review on functional beverages from cereal grains-characterization of nutraceutical potential, processing technologies and product types

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ABSTRACT

Due to growing consumer interest in fitness and wellbeing, foods and beverages with therapeutic and functional qualities are in higher demand. In addition to being significant staple crops and major providers of nutrition and energy, cereals are rich in bioactive phytochemicals with health benefits. Cereal grains offer a lot of promise for processing into functional beverages since these include a wide variety of bioactive phytochemicals such as phenolic compounds, carotenoids, dietary fibres, phytosterols, tocols, gamma-oryzanol, and phytic acid. Despite the fact that a wide variety of beverages made from cereal grains are produced globally, they have received very little technological and scientific attention. The beverages confer replacements for milk made from cereal grains, roasted cereal grain teas and fermented non-alcoholic cereal grain drinks. This review emphasizes on the three primary kinds of functional beverages made from cereal grains. Further, the potential applications and directions for the future related to these beverages are discussed with elaborated processing methods, health benefits and product attributes. Cereal grain-based beverages may represent a promising new class of healthy functional beverages in our daily lives as the food industry gets more diverse.

1. Introduction

The diet of the majority of the people mostly includes cereals and their derivatives as a main source of calories and nutrients, both in developing, as well as in developed nations [1]. Cereals are grasses of the *Poaceae* family that are grown for the edible parts of their grain or seed (caryopsis) [2]. Several grains from non-grass families (like, quinoa from the *Amaranthaceae* family, buckwheat from the *Polygonaceae* family) are usually grouped with cereals despite being scientifically classified as pseudocereals. In terms of total production, according to Food and Agricultural Organization (FAO), corn, sorghum, rye, barley, wheat, buckwheat, millet, rice, as well as oats are the world's principal cereals [Xiong et al., 2020]. As a large source of good macronutrients and micronutrients, as well as

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Table 1
Major bioactive phytochemicals in whole cereal grains.

Cereals	Bioactive phytochemicals									References
	Phenolic acids	flavonoids	Other phenolics	Dietary fibre	carotenoids	Tocols	Phytosterols	Gamma-Oryzanol	Phytic acid	
Buckwheat	Caffeic acid Salicylic acid *p*-Hydroxybenzoic acid	Flavonols	Lignans	b-glucans resistant starch	n/a	Alpha-Tocopherol Gamma-Tocophero	Sitosterol Campestero	n/a	Phytic acid	[11]; Xiong et al., 2020
Rye	Ferulic acid *p*-coumaric acid Sinapic acid	Anthocyanidins	Lignans Alkylresorcinols	b-glucans Arabinoxylans resistant starch	n/a	Alpha-Tocopherol beta-Tocotrienol	Sitosterol Campesterol	Gamma-Oryzanol	Phytic acid	Gambus et al., 2015
Oats	Ferulic acid Sinapic acid	Flavones Flavonols Flavanones	Lignans Avenanthramides	b-glucans Arabinoxylans resistant starch	carotenoids	Alpha-Tocopherol Alpha-Tocotrienol beta-Tocotrienol	Sitosterol Campesterol	n/a	Phytic acid	Gani et al., 2012; Xiong et al., 2020
Millet	Ferulic acid *p*-coumaric acid	Flavones	Condensed tanins Lignans Alkylresorcinols	b-glucans Arabinoxylans resistant starch	Lutein Zeaxanthin	Alpha-Tocopherol Gamma-Tocopherol	Sitosterol Campesterol	n/a	Phytic acid	[12]
Sorghum	Ferulic acid *p*-coumaric acid Sinapic acid Caffeic acid Salicylic acid	Anthocyanidins Flavones Flavonols Flavan-3-ols Flavanones	Condensed tanins	b-glucans Arabinoxylans resistant starch	Lutein Zeaxanthin Beta-carotene Beta-cryptoxanthin	tocol	Sitosterol Campesterol stigmasterol	n/a	Phytic acid	[13]
Barley	Ferulic acid *p*-coumaric acid	Anthocyanidins Flavan-3-ols	Condensed tannins Lignans Alkylresorcinols	b-glucans Arabinoxylans resistant starch	Lutein Zeaxanthin	Alpha-Tocopherol Alpha-Tocotrienol beta-Tocotrienol	Sitosterol Campesterol	Gamma-Oryzanol	Phytic acid	[14]
Wheat	Ferulic acid *p*-coumaric acid Sinapic acid Caffeic acid	Anthocyanidins Flavones	Lignans Alkylresorcinols	b-glucans Arabinoxylans resistant starch	Lutein Zeaxanthin Beta-carotene	Alpha-Tocopherol beta-Tocopherol beta-Tocotrienol	Sitosterol Campesterol	Gamma-Oryzanol	Phytic acid	[15]
Rice	Ferulic acid *p*-coumaric acid	Anthocyanidins Flavones	Lignans	b-glucans Arabinoxylans resistant starch	Lutein Alpha-carotene Beta-carotene	Alpha-Tocopherol Alpha-Tocotrienol	Sitosterol Campesterol stigmasterol	Gamma-Oryzanol	Phytic acid	[16]
Corn	Ferulic acid *p*-coumaric acid Sinapic acid	Anthocyanidins Flavonols flavan-3-ols	Lignans Alkylresorcinols	b-glucans Arabinoxylans resistant starch	Lutein Zeaxanthin Alpha-carotene Beta-carotene Beta-cryptoxanthin	Alpha-Tocopherol Gamma-Tocopherol Alpha-Tocotrienol gamma-Tocotrienol	Sitosterol Campesterol	Gamma-Oryzanol	Phytic acid	[17]

having significant concentration of bioactive phytochemicals that could possess health-promoting characteristics, cereals are considered to be the important components of the human diet [3]. Extra-nutritional ingredients like carotenoids, phytosterols, phenolic components, as well as dietary fibres are bioactive phytochemicals found in modest amounts in plants (Xiong et al., 2020). These bioactive components frequently perform specialized functions in human physiological activities such as anti-inflammatory, antioxidant, immune system augmentation, hormone modulation and so on (Johnson 2013) [4]. The availability of these bioactive components in grains benefits human health and is thus extremely significant.

Today, flavour alone is not enough to please consumers who want high-quality, nutrient-dense beverages. As a result, non-alcoholic beverage firms have converged on low or no-calorie drinks and have placed an emphasis on organic components in non-alcoholic beverages. Functional foods are the foods that, in addition to their essential nutrients, contain biologically active components in sufficient proportions to benefit the consumer's health. Beyond standard nutrition, these foods typically contain health-promoting components [5]. The prominent class of functional foods are the functional beverages since they allow the addition of desirable nutrients and bioactive substances to maintain hydration while also having anti-aging, energy-supplying, soothing, or beauty-enhancing properties [6]. Cereals were traditionally been employed to produce a range of locally consumed, health-promoting beverages for local use in different parts of the world. However, compared to beverages made from fruits, vegetables, or medical herbs, cereal grain-based beverages have received far too little attention. Cereal fermentation produces volatile molecules such as alcohols, organic acids, aldehydes, ketones, as well as carbonyl components, all of which contribute to a complex flavour and taste profile that makes the product highly appealing (Kokwar et al., 2021). Previous studies have suggested that oats have health-promoting properties, as well as a significant nutritional value. Besides this, it possesses significant quantity of dietary fibre, such as cellulose, glucan and arabinoxylan [7], as well as vitamins, minerals and phytochemicals (avenanthramides) [7].

Hordeum vulgare (barley) has a low-fat content and is high in vitamins and antioxidants. The consumption of barley glucans is linked to immune stimulant activities, as well as the reduction in cholesterol, plasma glucose and risk of colon cancer. Buckwheat (*Fagopyrum esculentum*) is a pseudo-cereal that is underutilized but has a lot of capability as a useful ingredient in wide variety of foods. Catechins, rutin, or other polyphenols, that have considerable dietary advantages, contribute to its strong antioxidant activity. Rice (*Oryza sativa*) is a staple food that comes in two varieties-pigmented and non-pigmented. The dark-red pigmented rice may provide beneficial health effects owing to its high dietary fibre content that may aid in lowering the glycaemic index (GI), hence lowering the risk of onset of diabetes in adults (Kokwar et al., 2021).

The present review intends to give a thorough review on nutraceutical components of cereal based functional beverages in addition to providing the information on processing technologies and product characteristics.

1.1. Bioactive components in cereal grains

The health and functional properties of cereals, as well as cereal-based products are primarily due to their bioactive phytochemicals. High concentration of phytochemicals in cereals gives credence to their wide range of health benefits. Whole-grain cereals contain phenolic compounds, ϒ-oryzanol, β-glucan, carotenoids, phytosterols, tocols, phytic acid, vitamins and minerals [8]. The researchers are more focusing towards the beneficial health effects of raw cereal grains, grain extracts and specific phytochemicals extracted from cereal grains [9]. Despite the fact that food processing inevitably destroys several phytochemicals and reduces their beneficial health properties, some processing techniques and procedures are able to minimize these losses. Moreover, these strengthen various bioactive molecules through the formation of new bioactive components and releasing the bound bioactive components [10]. Table 1 updates and outlines the major groups and most common sub-categories of bioactive substances in the cereals (corn, rice, barley, wheat, sorghum, oat, rye, buckwheat and millets).

1.1.1. Phenolic compounds

Polyphenols, also known as phenolic components, are a broad class of chemical components that contain one or more benzene rings having hydroxyl groups. Flavonoids, tannins, phenolic acids, coumarins and lignans are examples of phenolic components present in plants. Cereals contain phenolic components like lignans, flavonoids, phenolic acid, avenanthramides (unique group of polyphenols in oats) and alkyl resorcinol [8]. In cereals, phenolic compounds are the primary antioxidant source. The most prevalent phenolic components are flavonoids and phenolic acids, with the highest concentrations found in buckwheat (506–1642 mg GAE/100 g) and sorghum (87–2960 mg GAE/100 g) [18].

1.1.2. Phenolic acids

The two subgroups of phenolic components known as hydroxybenzoic acids (hydroxybenzoic, galic, p-syringic, protocatechuic and vanillic acids) and hydroxycinnamic acids (caffeic, *p*-coumaric, sinapic and ferulic acids) are collectively referred to as "phenolic acids" [19]. According to previous studies, flavour of cereal foods is said to be caused by soluble phenolic acids [8]. The two principal cereals with the highest phenolic acid contents are millet (61–391 mg/100 g) and sorghum (39–285 mg/100 g) [20].

Phenolic acids can be either free or bound. Most of the phenolic acids found in cereals are covalently linked to cell walls and are essential to their structures, necessitating the breakdown of covalent bonds to facilitate their extraction. In contrast, free phenolic acids are primarily present in the pericarp's outer layer, thus can be extracted using organic solvents [21]. Except for buckwheat, all common cereals include ferulic acid, which is the prevalent phenolic acid. It is mostly found bonded in the cell wall of bran portion [9,18]. Ferulic acid has been found to be present in the highest proportions in wheat and maize, making up as much as 90% of the total concentration of phenol of whole grains [22].

1.1.3. Flavonoids

The bran portion of the grains contains highest concentrations of flavonoids, which make up the most abundant phenolic compound family found in environment and cereal grains [23]. The most prevalent flavonoids found in cereals are flavonols, flavones, falvan-3-ols, anthocyanidins and flavanones. Of all the cereal grains, sorghum has the widest range and most widespread flavonoids [24]. Majority of the studies on flavonoids in cereals have focused on anthocyanidins, a group of water-soluble pigments. Cereals possess a wide range of anthocyanidin concentrations.

1.1.4. Other phenolics

Condensed tannins (also known as proanthocyanidins or procyanidins) are polymeric phenolic components. These are primarily present in pigmented cereal grains, like red finger millets, brown sorghum and dark-colored barley and are primarily made up of flavan-3-ol monomers [25]. Condensed tannins in sorghum have significant degree of polymerization and higher molecular weight, which are not found in other major cereals; however, these are present in significant amounts in sorghums with pigmented testa (type-III high tannin sorghums) [26]. Condensed tannins are considered to be anti-nutritional compounds but are believed to have astringent and bitter taste [26]. Lignans are phytoestrogens found in various plants and are present in brans of cereal grains. These are also found in higher amounts in rye and oats (Rodriguez-Garcia et al., 2019). Cereal lignins have also been widely studied and 7-hydroxymatairesinol has been discovered in millet, wheat, triticale, oat, bran, barley, corn, as well as in amaranth whole grain. Syringaresinol is another lignin present in cereals [8]. A class of phenolic lipids known as alkylresorcinols, have been recorded in cereals such as corn, millet, barley, wheat, as well as rye, with rye having the largest concentration. These are mostly found in the bran portion of cereal grains [20]. The phenolic alkaloids known as avenanthramides, a unique group of polyphenols, are only found in oats. The primary avenanthramides found in oats are avenanthramides A, B and C.

1.2. Carotenoids

The group of natural pigments known as carotenoids, widely distributed in plants, gives them their yellow, orange and red colours. Carotenoids are lipophilic bioactive components that are more equally distributed inside the cereal grains than any other bioactive components such as phenolic compounds [27]. Carotenoids contribute significantly to the yellow hue of endosperm of cereal grains [28]. The germ and bran regions contain majority of bioactive compounds, more concentrated in the aleurone layer [28]. Zeaxanthin, lutein, α-carotene, β-carotene and β-cryptoxanthin are the primary carotenoids found in cereals. The concentration, as well as composition of these carotenoids in grains varies significantly [29,30].

Given that the cereals have lower amounts of carotenoids than fruits and vegetables do, yellow-genotype corn (*Zea mays*) has the highest concentrations (up to 63 μg/g) of these phytochemicals. Owing to their lipid-soluble antioxidant or pro-vitamin qualities, carotenoids have drawn a lot of interest.

1.3. ϒ-Oryzanol

Phytosterol esters of transferulic acid (*trans*-hydroxycinnamic acid) make up the majority of ϒ-oryzanol, a combination of ten esters of triterpene alcohols. It is an antioxidant which has been linked to the reductions in platelet aggregation, cholesterol absorption and plasma and serum lipid levels [31]. Numerous researchers have looked into how germination process affects the amounts of component, ϒ-oryzanol. It has been investigated that the concentration of ϒ-oryzanol in brown rice increases when the grain germinates [31].

1.4. Phytic acid

The main phosphorus reserve in cereals and legumes is phytic acid (PA), which supports the biosynthetic requirements of developing tissues during germination [32]. The term "phytate(s)" is/are used to refer to phytic acid salts, which are the storage form of phytic acids [32]. Phytic acid is more concentrated in aleurone layer and germ portion of the grain. Phytic acid makes up 1–7% of the dry weight of the whole grain and it also includes more than 70% of the total phosphorus in it (Xiong et al., 2020). It can bind to proteins, carbohydrates, minerals and other nutrients, thereby reducing their bioavailability. The human body lacks endophytases, as a result, phytates cannot be broken down inside our body or taken up in the small intestines. Therefore, the chelated minerals in phytic acid are not bioavailable, which is why it is typically regarded as an anti-nutritional component present in grains [33]. Additionally, because of the capacity of phytic acids to bind minerals, it can be utilized in a number of applications related to food quality, including preserving the green color of vegetables, minimizing lipid peroxidation, or enzymatic browning in fruits and vegetables [32]. Phytic acid also shows some favourable effects like antioxidant activity, stimulation of DNA repair, disruption of cellular signal transduction, etc. [34].

1.5. Dietary fibres

One of the main and prevalent components of cereals that promotes health is dietary fibre, belonging to another family of bioactive phytochemicals. Cereals are a significant source of dietary fibre, making up roughly 50% of the total amount consumed in western countries [35]. Dietary fibre is mostly found in bran and endosperm parts of cereal grains (Joye et al., 2020). These may be described as naturally occurring carbohydrates with degree of polymerization as three or higher, that naturally occur in foods of plant origin and are not digested and absorbed in small intestine (Prasadi and Joye, 2020).

Dietary fibre is grouped into two types- (1) soluble dietary fibre (SDF), (2) insoluble dietary fibre (IDF) [11]. Non-cellulosic polysaccharides and oligosaccharides make up SDF in a variety of forms for example, pectin, water-soluble gums or β-glucans [36]. Water-insoluble hemicellulose, cellulose, as well as lignin are amongst the structural cell wall constituents of plants that make up IDF. It has been reported that SDF reduces overall intestinal enzymatic activity, thereby, lowering the post-prandial plasma glucose levels (Prasadi, 2020). The synthesis of short chain fatty acids (SCFAs), that have a significant role in the control of cardiovascular diseases (CVDs), is also increased by SDF owing to their high fermentability [37]. IDF, on the other hand, primarily acts as a laxative and bulking agent, increasing faecal mass or shortening intestinal transit time. Enhanced satiety or a decrease in body weight could also be linked to an IDF mechanism for managing non-communicable diseases (NCDs) [37]. SDF and IDF both work to relieve constipation, lessen bile salt reabsorption and reduce the risk of colon cancer (Prasadi and Joye 2020).

β-Glucans are other classes of polysaccharides made up of glucose units. D-glucose monomers are joined together by glycosidic linkages to form *β*-glucan at positions (1–3), (1–4) and (1–6) [8]. These are significant dietary fibres that are primarily found in the aleurone or endosperm cell walls of all major cereals (Joye et al., 2020). The largest concentrations of *β*-glucans amongst the major

Table 2
World's most popular non-alcoholic beverages from cereal grains.

	Cereals	Name of beverages	Regions	Description of beverages	References
Milk type	Corn	Corn milk	China	- Lactose-free -Hypoallergenic - Yellow color	Xiong et al., 2020
	Rice	Rice milk	East Asian countries	- Lactose-free - Hypoallergenic (best) - Milk-like	[42]
	Oat	Oat milk	Western countries	- Lactose-free - Hypoallergenic - Milk-like	[43]
Tea type	Corn	Corn tea, yumi-cha, oksusu-cha	China, Kore	- Caffeine-free - Clear, yellow color - Light, mild, sweet taste	Xiong et al., 2020
	Rice	Brown rice tea, caomi-cha, hyeonmi-cha	China, Korea	- Caffeine-free - Clear, yellow to brown color	[44]; Xiong et al., 2020
	Barley	Barley tea damai-cha, boricha, mugi-cha	China, Korea, Japan	- Caffeine-free - Clear, yellow to brown color - Light, slight bitter and sweet taste - Roasted, nutty aroma	[45,46]
	Sorghum	Sorghum tea, gaoliang-cha	China	- Caffeine-free - Clear, light yellow color - Roasted, floral, nutty aroma - Caffeine-free	[13]
	Buckwheat	Buckwheat tea, kuqiao-cha, memil-cha, soba-cha	China, Korea, Japan	- Caffeine-free -Clear, light yellow color - Rich, slight sweet taste - Roasted, rich, nutty arom	[11]
Fermented non-alcoholic	Corn	Mahewu	South Africa, Zimbabwe	- Sweet-sour, thin, gritty	García et al., 2022; Marquez et al., 2021
		Pozol	Mexico	-Light-grey or whitish color	
	Rice	Amazake	Japan	-Sweet-sour, milky - Brownish color	Nagao and Sata 2013
	Sorghum	Busher	Uganda	- Sweet or sour -Opaque, brownish color	Xiong et al., 2020
	Sorghum	Gowe	Benin	Sweet-sour, light, smooth -Brownish, reddish color	Xiong et al., 2020; Seïdou et al., 2011
	Millet	Kunun-zaki	Nigeria	-Sweet-sour, milky, creamy and smooth -Light-brown or whitish color	Xiong et al., 2020
	Rye	Kvass	Eastern and Central Europe	-Sweet-sour taste, a mixed rye bread and yeast flavor, –Golden brown color	[47]
	Wheat, maize, barley, oats	Boza	Turkey, Greece, Bulgaria	-Sweet taste, color varying from creamy white to light brown	Alan et al., 2014
	Millet or rice	Busa	Syria, Kenya	Sweet taste, color is dark brown	Alan et al., 2014
	Sorghum, maize	Gowe	Africa	produced by Lactobacillus ferm	Laurent Adinsi et al., 2017
	Wheat, sorghum	Kunun-zaki	Nigeria	low viscosity, creamy appearance; sweet-sour taste	[48]
	Sorghum, millet, maize	Obushera	Uganda	moderately thick composition, pale brown color; sweet and sour taste; pH $<$ 4.5	Fatma et al., 2017
	Wheat	Shalgam	Turkey	Red in color, sour taste	Fatma et al., 2017
	Maize, finger millet	Togwa	Zimbabwe, Africa	Opaque and brownish color; sweet, sour taste; pH ~4	Deborah et al., 2014

cereals are found in the endosperm and aleurone layer of oat and barley plants, respectively [38]. Arabinoxylans are a particular class of hemicellulose that have arabinose substitutions in their linear xylose backbone chain. All of the major cereals have been found to have arabinoxylans, however, rye has the highest concentration (Joye et al., 2020). Arabinoxylans are unique since these contain phenolic acids like ferulic acid, which are covalently bound to xyloses or arabinoses. Ferulated arabinoxylans have drawn the attention of the pharmaceutical sector due to their anti-cancer, prebiotic and antioxidant properties (Mendez-Encinas et al., 2018).

2. Cereal based functional beverages

The cereal based functional beverages are usually of three types- (1) cereal-based milk substitutes, (2) cereal-based teas and (3) fermented non-alcoholic beverages.

2.1. Cereal based milk substitutes

Cow milk has long been a significant part of daily human diet across the world. However, there is a fast-expanding market for plant-based milk substitutes due to milk allergies, lactose intolerance, environmental or ethical concerns associated with them, therefore, shifting the lifestyle towards a healthier and more plant-based diet [39]. Additionally, changing lifestyles including preferences for vegetarian and vegan diets, environmental concerns and ethical objections to drinking cow milk significantly impact the demand for plant-based milk substitutes. As a result, people believe that these options will help them feel healthier and achieve their wellness goals [40]. To substitute cow's milk, a number of plant substitutes have been used over the past 20 years, but soy and almond milk have received the most attention (Xiong et al., 2020). Plant-based milk alternatives are liquids made by dissolving plant material (such as cereals, legumes, pseudo-cereals, oilseeds or nuts) after pulverization into water. After that, these fluids are homogenized, producing particles with diameters ranging from 5 to 20 μm, the consistency of which resembles to that of cow milk [41]. Conclusively, cereals are gaining their importance for their use in the development of functional milk substitutes owing to their potential of offering numerous health benefits (Table 2).

2.1.1. Types of cereal-based milk substitutes

Presently, the following types of milk substitutes are prepared.

2.1.1.1. Corn milk. In India, corn is a major food crop the composition of which includes starch, sucrose, fibre and pentosan [49]. It is a kind of cereal milk which has recently entered the Chinese market. Owing to its high bioactive components including dietary fibre and proteins, corn-based milk is thought to prevent cardiovascular illnesses, obesity and diabetes (Xiong et al., 2020). The process of making corn milk normally involves preheating, milling, blending, enzymatic hydrolysis (saccharification), homogenizing, then pasteurizing the corn milk, which is frequently done using sweet corn [50]. Because of its pleasant flavour or nutritional content, corn milk offers a good choice to lactose-intolerant people and to those who are concerned about the presence of saturated fats in cow milk. Apart from milk, the other products that could be made include corn milk powder, corn yoghurt, corn flakes, etc. That may offer several health benefits due to their low cholesterol levels [49].

2.1.1.2. Rice milk. Rice, belonging to grass family is frequently grown for its seed [51]. Rice water, a by-product of cooking or boiling rice, is what is traditionally referred to as "rice milk." It can also refer to the liquid that floats on top of rice porridge, a classic mealtime beverage that satisfies thirst and increases appetite (Xiong et al., 2020). Rice milk is a plant-based milk substitute that provides consumers with milk alternatives embodied with nutritional benefits due to higher carbohydrate content and less fat.

Broken rice, which is the primary by-product of rice industry, can be used to create value-added goods that will help to improve the remunerative returns to the rice millers [51]. Nearly, 90% of rice is made up of starch and 10% of it is protein and contains neither threonine nor lysine. Rice lacks the precursor to vitamin A i.e., β-carotene [16]. Commercial rice milk is normally produced by grinding/milling rice, combining it with water followed by starch hydrolysis, filtering, fortification and homogenization. Rice syrup or whole grain brown rice are frequently used in its production (Xiong et al., 2020). The bran, which is removed when rice is processed into milk, contains more than 85% of the iron, an essential element, found in rice. Iron fortification of rice milk is, therefore, advised. However, due to their rich nutrient profile and underutilization, companies are increasingly concentrating on the manufacture of rice bran milk [30]. Higher fat content and lipase activity may however, be the challenge that must be addressed.

2.1.1.3. Oat milk. Oats (*Avena sativa*), a member of *Poaceae* family, are typically classified as minor cereal crop (Syed et al., 2019). Owing to its possible medicinal advantages, oat milk has only recently become popular in the market. Oats have received much interest due to their significant dietary fibre content, nutritional value or phytochemical content. Oats are considered as one of the most interesting raw materials for producing functional plant-based milk substitutes due to their higher dietary fibre, functional proteins, β-glucan, lipid or carbohydrate components, besides possessing other nutraceutical components that confer several health benefits. Such health benefits include anti-inflammatory or hypocholesterolaemia characteristics [41]. The presence of β-glucan, a functionally active component, with potential nutraceutical uses present in oats, is attracting the consumers towards oat-based milk substitutes. β-Glucan is a soluble fibre and has the capacity to raise viscosity of solution, which in turn delays the time at which the stomach empties, or it could be said that it lengthens the time that the intestines take to empty. These effects are further linked to lower blood sugar levels [41]. It is a rich source of cellulose, arabinoxylans and other glucans. The most popular and commercialized cereal milk is presently oat milk, which is sold under numerous brands (Xiong et al., 2020). The milk is provided in compact tetra packs in different sizes after ultra-high treatment process (Syed et al., 2019).

2.1.2. Nutritional characteristics of cereal-based milk substitutes

Cereal based milk is a possible substitute to already available animal-based milk such as cow's milk. It is hypoallergenic, lactose-free and also includes the bioactive components with potential health-promoting abilities. Contrary to cow's milk, it often lacks a balanced nutritional profile and confronts a number of technological obstacles in terms of processing and product durability (Xiong et al., 2020). People who replace cow's milk by cereal-based milk alternatives, are more likely to experience nutritional deficiencies since these plant-based water-soluble extracts are not comparable to or nutritionally equivalent to cow's milk.

Cereal milk is undoubtedly higher in carbohydrates and dietary fibre than cow's milk, however, it lacks iron, calcium, vitamin A or some amino acids. As a result, cereal milk substitutes could not fully replace cow's milk for children under the age of five [52]. As a result, it is common practice to fortify/enrich plant-based drinks with necessary proteins, minerals or vitamins in order to utilize them fully as an alternative to cow's milk [41]. In comparison to cow milk, various fortified plant-based beverages available in the market provide an equivalent amount of calcium and vitamin D as cow's milk does (Silva et al., 2019).

2.1.3. Processing methods for development of cereal-based milk substitutes

Cereal milk substitutes are rich in starch content; therefore, thermal processing may face hurdles in creating a stable emulsion. Since, heat processing can cause starch to gelatinize, which results in milk having an increased viscosity or gel-like consistency, as well as a poor sensory quality and acceptability. Maltodextrins, which gelatinize at higher degrees and inhibit the gelation amid heat processing, are usually produced by enzymatic hydrolysis of starch by amylases or glucosidases, preserving the build-up of fluidity and consistency of milk substitutes [39]. It is possible to create a new product with enhanced nutritional properties that are similar to those of cow milk by combining two or more raw components.

The stability of the beverage can be improved by homogenization, which reduces sedimentation, thereby making it sure that the particles are dispersed equally. Another interesting method that can be used for plant-based milk is ultra-high-pressure homogenization (UHPH), a more recent and sophisticated homogenization technique that uses pressures of up to 400 MPa. UHPH can more successfully increase the quality, as well as stability of plant-based milk substitutes by producing smaller but more uniformly sized particles [53]. Additionally, it can reduce the number of microorganisms and inactivate enzymes, producing the results comparable to that of pasteurization (Xiong et al., 2020). The stability of cereal-based milk substitutes can also be increased by adding stabilizers or emulsifiers (Xiong et al., 2020). have recently advocated in their study that, adding 0.10% xanthan gum to rice-based milk substitutes enhanced its physical stability. The general steps for development of plant-based milk substitutes are given in Fig. 1.

The consumer desire for plant-based milk is expanding, which has opened up a new opportunity for utilization of cereals in their

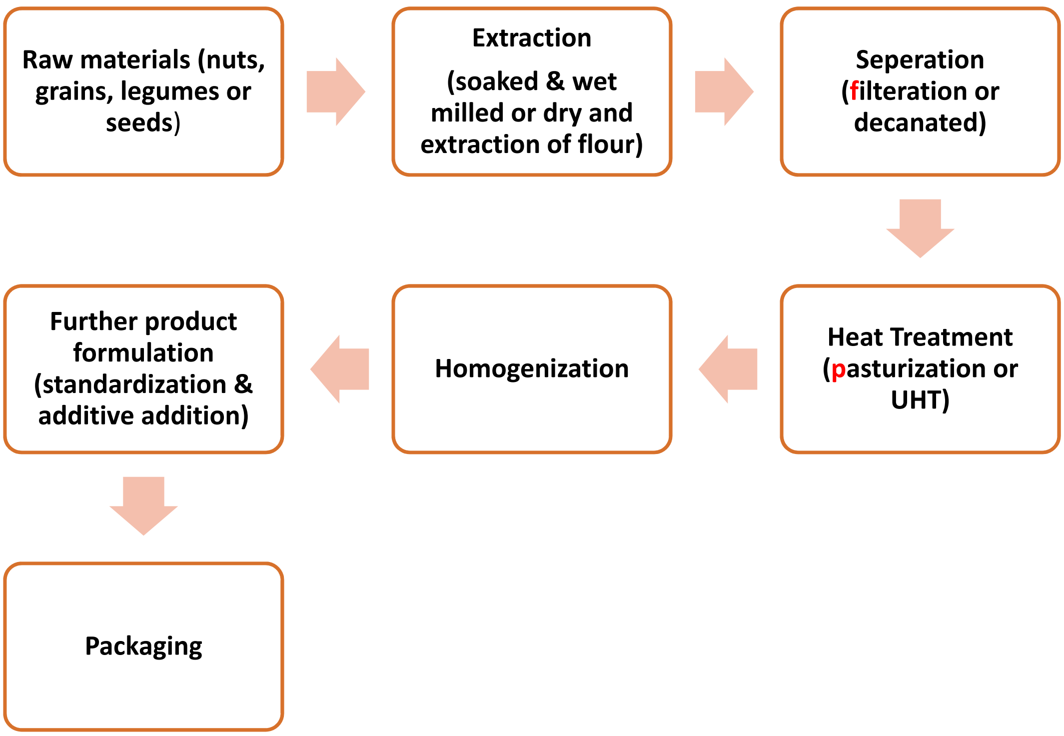

Fig. 1. General manufacturing steps in the production of plant-based milk substitutes Srikaeo, K. (2020). Biotechnological tools in the production of functional cereal-based beverages. In Biotechnological progress and beverage consumption (pp. 149–193). Academic Press.

development. Because of this, there is a significant chance to use cereals as cow milk substitutes. Even though milk made from cereal grains has several health benefits over conventional cow milk, the previously described technological or nutritional difficulties requires to be resolved until it can successfully replace cow milk [54]. Cereal based milk substitutes are also considered to be the possible alternative to cow milk in an age where people are gravitating toward plant-based diets.

2.2. Cereal based teas and their processing

A traditionally prepared beverage in East Asian countries, especially in Korea, China and Japan is a caffeine-free cereal grain-based tea (Table 2). Cereal grain tea is an infusion made from roasted grains since roasting generates the distinct aroma. Usually, the roasted whole grains or powder are boiled before being brewed in hot water or served either hot or cold (Xiong et al., 2020). A large proportion of thiamine and riboflavin can be lost when grains are roasted to darker colours at around 150 °C. The concentrations of acrylamide, an organic and water-soluble compound, in dark-roasted grains may likewise be very high. The main chemical process involved in the production of acrylamide is known as the ‘Maillard reaction’. It occurs naturally in cereal foods during high-temperature cooking processes such as frying, baking and grilling at temperatures above 120 °C and low humidity. Acrylamide consumption was linked to an increased risk of ovarian and endometrial cancer [55]. Also, exposure to acrylamide during pregnancy may have an effect on foetal growth parameters [56]. On the other hand, roasting also elevates the levels of phenolic compounds and thus antioxidant activity [57]. Due to the abundance of bioactive components in cereal grain tea, various health-promoting properties are thought to exist. These components in the tea soup, especially water-soluble ones, is what gives roasted cereal grain tea its health advantages. If the grain leftovers are in the soup or taken as a whole, there are even more health benefits.

2.2.1. The potential health benefits of cereal grain teas

2.2.1.1. Corn tea. Whole maize grains are used to make the traditional Korean tea known as corn tea. To make corn tea, grain is dried, roasted, then mixed with boiling water to produce a bright yellow tea. The majority of Korean homes drink this famous winter-time tea, which is thought to have thirst-quenching, detoxifying, as well as diuretic properties [57]. *Oksusu-cha* is the name of the tea brewed in Korea from roasted corn [57]. Due to the fact that roasting provides distinct aroma to beverage, it is therefore, an essential step in manufacturing of corn-based beverage. The conventional method of roasting and extracting maize kernels in Korea is to use hot water. Roasting maize grains improve food safety, as well as quality of intermediate or finished goods by boosting tastes, antioxidants contents and activity [17]. Gallic acid, caffeic acid, homogentisic acid, q-coumaric acid, naringin, ferulic acid, hesperidin and myricetin are the phenolic acids that have been found in the roasted maize [17].

2.2.1.2. Brown rice tea. Brown rice is a popular whole grain since it includes higher levels of water-soluble components [58]. Brown rice that has been roasted properly may develop a distinct flavour making it more popular with consumers. Over 300 volatile chemicals, including ketones, aldehydes, esters, alcohols and heterocycle compounds, have so far been found in all types of rice [58]. The quality of finished goods is also significantly impacted by changes in microstructure brought about by roasting. Soaking could hasten the changes in microstructure, the release of fragrance molecules and the dissolution of nutrients that are soluble in water (Xiong et al., 2020). *Hyeonmi-cha*, a type of toasted grain, is frequently used in Korea (brown rice tea). A beverage called *sangnyung* is prepared from burned rice. When rice (usually white rice) on the bottom of the pot has reached a burnt crust, water is immediately poured to the pot. In contrast to *hyeonmi-cha*, the rice grains are cooked for a considerable amount of time until they become soft, a point at which they can be swallowed along with the liquid [57].

2.2.1.3. Barley tea. Barley, one of the world’s oldest grains, is a key ingredient in several regional cuisines. Numerous bioactive phytochemicals with potential health benefits are abundant in barley [14]. Traditional refreshing drink called barley tea is popular in China, Japan, Korea and other countries. Barley tea, also referred to as “Oriental Coffee”, has a pleasant aroma [14]. The therapeutic properties of barley tea have long been documented in the Chinese medical dictionary, Materia Medica, claiming that it can clear the stomach, aid in digestion and remove oil. According to previous research, barley tea may improve blood fluidity and raise skin warmth and cutaneous blood flow [46]. The scavenging of free radicals, as well as the chelation of transition metal ions supports that the alcoholic and/or aqueous phenolic extracts from roasted barley tea grain displays significant antioxidant activities *in-vitro*. The primary antioxidants in barley tea are phenolic compounds and some of these molecules have demonstrated better antioxidant properties *in-vitro* as compared to synthetic antioxidants, butylated hydroxytoluene (BHT) [59]. Against *Streptococcus mutans,* barley tea exhibited potent anti-adhesive properties [14]. These results imply that, drinking barley tea might limit cariogenic bacteria from colonizing tooth surfaces or improve oral health. Blood cholesterol is also believed to get lowered with barley tea [14]. As an alternative to coffee, roasted barley tea is supplied in ground form, occasionally mixed with chicory or other ingredients (barley coffee). Barley coffee is being frequently and widely consumed by Europeans. When combined with milk, it is frequently served to kids as a breakfast beverage in Italy where it is recognized as coffee d’orzo. *Inka*, which was created in Poland in the late 1960s, is another well-known roasted grain beverage. Rye, chicory, barley, or sugar beet are all roasted together to create Inka, a caffeine-free substitute to coffee. In this, cereals make up around 72% of the mixture [57].

2.2.1.4. Sorghum tea. Sorghum (*Sorghum bicolor* L. *Moench*), a grain crop indigenous to North-Eastern Africa, is the fifth most widely grown grain crop in the world. Depending on the variety, it may contain substantial amounts of a number of phenolic compounds such as flavonoids, phenolic acids, as well as condensed tannins [13]. Regular sorghum eating may lower the risk of contracting certain illnesses like cancer, heart disease, or type-II diabetes. Consequently, there is a growing demand in utilizing sorghum to create functional foods that promote health [13]. Raw sorghum grains must be soaked, steamed then roasted to produce sorghum grain tea. Each treatment may have an impact on bioactive chemical content. Roasting increases the phenolic profile of sorghum [60]. The increase in phenolic content is due to the liberation of bound phenolic acids from cellular components and cell walls and disintegration of some conjugated polyphenolics into simple phenolics [60]. Sun et al. [61] used whole grain of red sorghum which had been steamed and roasted after being fermented using yeast (*Saccharomyces cerevisiae*) or lactic acid bacteria (*Lactobacillus plantarum*).

2.2.1.5. Buckwheat tea. Another common grain tea is buckwheat tea which has recently gained popularity in Korea, China and Japan owing to its peculiar roasted aroma and beneficial health effects. This tea is usually brewed using roasted whole grains, hot water infusion, or boiling, as well as other non-grain ingredients like buckwheat leaves and stems are commonly used. In this regard, buckwheat tea is comparable to other teas made from cereal grains (Xiong et al., 2020). Buckwheat excellently balances nutritional and functional elements and culinary and medical industries are becoming more and more interested into it. Due to its well-balanced amino acid composition and hypolipidemic properties, proteins from buckwheat are superior to those from several other cereal grains [11]. Buckwheat flavonoids have demonstrated significant health advantages including hypocholesterolemic, hypoglycaemic and antimicrobial properties. The leaves and flowers of buckwheat were discovered to contain fagopyrin, a phototoxic chemical that may cause skin photosensitization, especially in livestock [11]. Buckwheat tea is made from both ordinary and Tartary buckwheat kinds, but Tartary buckwheat is more often consumed due to its higher phenolic content (Xiong et al., 2020). Tartary buckwheat (*Fagopyrum tataricum*) is being widely consumed by people through the world [11]. Buckwheat tea could be broadly grouped into two types-whole plant tea (WPT) and whole grain tea (WGT) [11]. Numerous buckwheat products, including whole grains, germinated grains, de-branched grains, bran, or entire plant (leaves, whole grain, or steams), are now commercially accessible. These products are processed using a number of techniques, including soaking, steaming, drying, roasting and extrusion [62]. Various processing techniques have considerable effect on buckwheat and chemical composition of its products. To increase the health beneficial characteristics of buckwheat grain tea, efforts have already been made to strengthen it with herbal tea ingredients [62]. Xiong et al., 2020 have reported the higher levels of catechin and total flavonoids in fortified buckwheat tea than the control (buckwheat tea only).

2.3. Fermented non-alcohol cereal beverages and their processing

Currently, “non-alcoholic” is a regulatory term and the laws regarding it vary across the globe. For instance, EU Regulation No. 1169/2011 specifies plainly that, if a beverage has an alcoholic strength by volume (ABV) of more than 1.2%, it must be labelled as an alcoholic drink. Numerous non-alcoholic cereal fermented beverages with similar names and features are sold all over the world as alternatives to alcoholic drinks and for their similar thirst-quenching qualities, nutritional benefits and cultural importance. Everywhere in the world, especially in poor nations, fermented beverages made from grains are produced in a similar way, usually employing spontaneous microbial cultures [63]. Despite the fact that there are many non-alcoholic cereal fermented beverages with unique chemical profiles and sensory characteristics, all of them contain specific therapeutic and bioactive substances that are good for human health. It is challenging to determine the functional impact of the accessible and identified functional components in non-alcoholic cereal based fermented beverages (NFCBs) when consumed frequently [64]. When cereals are deficient in particular nutrients, additional food matrices can be added to improve the final NFCB, as was the case when *Moringa oleifera* leaf powder was added to mahewu to increase the Ca and Fe contents. A non-alcoholic beverage made of green tea and barley malt wort for its excellent amino acid content is another illustration of a functional NFCB. The nutritional content, functional qualities, texture, taste,

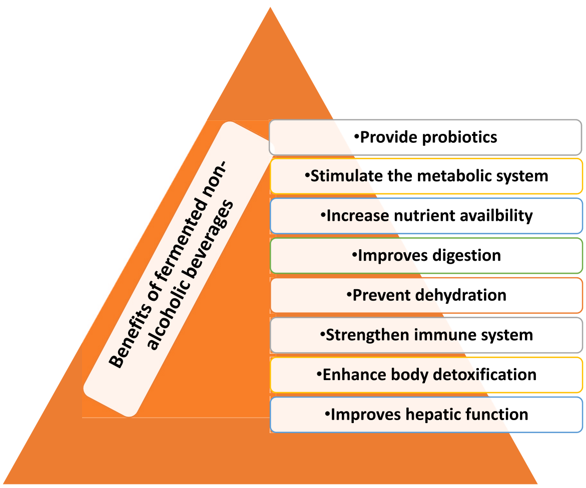

Fig. 2. Benefits of fermented non-alcoholic beverages.

digestibility, shelf life and flavour of beverages are all enhanced by fermentation. The fermented beverages derived especially from cereals are of prime importance since these grains provide an excellent substrate for fermentation and may also have some useful properties due to the presence of some nutrients that bacteria can readily absorb. Soaking, sprouting, malting, boiling, grinding and filtering are some of the processing steps that might be used [63]. Numerous parameters, including fermentation length, temperature, pH, grain moisture content, growth factor requirements, cereal nutrients, etc. affect the fermentation of cereals and must be controlled using technological means to ensure consistent quality [64].

Affordable fermented drinks are produced using conventional techniques that uphold product quality, security and hygienic standards. The fermentation process is influenced by lactic acid bacteria, which also results in lowering of pH that makes it impossible for lethal bacteria to grow. This lengthens the shelf life and improves product safety [63]. Probiotics are mixed cultures of different potentially helpful bacteria that are used in traditional methods. Additionally, it has been demonstrated that fermentation enhances the bioavailability of minerals, as well as other micronutrients and the digestibility of proteins [64].

The cereal-based non-alcoholic fermented beverages that have received the greatest attention are highlighted in Table 2. Fermented beverages are regarded as essential due to their nutritional, nutraceutical and medicinal benefits, as well as the fact that they transport healthy microbes that are essential for maintaining human health. These beverages could potentially lessen the negative health and economic impacts of poor diets. Its overall health benefits are illustrated in Fig. 2. Various types of cereal-based fermented non-alcoholic beverage are discussed briefly below.

2.3.1. *Fermented corn beverages*

Several communities in Southern Mexico and Guatemala still enjoy the ancient pre-Hispanic liquor known as *pozol*. It is a product of the fermentation of corn (*Zea mays* L.), which has roots in Mayan civilization. It has been consumed by the Mayan culture as a nourishing food and a daily beverage from pre-Hispanic times. It is also used in rituals and festivities (Marquez et al., 2021). According to Lasso and Trabanino (2018); it is currently consumed in Chiapas, Tabasco, Quintana Roo, Yucatan, Guerrero, Veracruz and Oaxaca. Furthermore, its use in various areas was thought to offer therapeutic benefits. Like, the Mayans utilized pozol to cure problems related to gastro-intestines such as diarrhoea and skin diseases, while the Lacandones used it to lower fever (Marquez et al., 2021). As it was done in pre-Columbian times, pozol is still being prepared and consumed. Dry corn kernels are boiled in water containing calcium oxide or lime. While cooking times vary by area, however, it typically ranges from 0.50 to 3.0 h followed by soaking for 3–14 h (Marquez et al., 2021). After boiling, the kernels are cleaned, stripped off from their shells to produce a consistent dough which is then uniformly wrapped into little balls and kept in banana leaves until fermentation is finished. Fermentation can take a few hours to as long as 30 days. The dough is then solubilized, combined with water and consumed like other beverages (Xiong et al., 2020).

A typical South African beverage derived from cornmeal is called *mahewu*. It is a thin, grippy and tart beverage. *Mahewu* is usually made by simply cooking maize porridge, which is then allowed to cool and fermented for 1–2 days at room temperature [65]. Several cereals including millet, sorghum or wheat are usually added amid the fermentation, which is a spontaneous procedure using natural bacteria. Lactic acid bacteria and also yeasts are the two primary microorganisms that have been isolated from mahewu (Xiong et al., 2020).

2.3.2. *Fermented rice beverages*

In terms of cereals, rice stands out because of its starch quality, mineral content, low glycemic index and antioxidant activity. Scientific studies have proven that rice has starches of higher digestibility, high concentrations of fatty acids, high biological value of amino acids and selenium and anti-hypertension activity. In context to this, rice can be seen as a food having potential uses [66]. Rice-based beverages are a rare type of food products that are only found in a few tropical regions of Asia-Pacific countries, in contrast to alcoholic beer derived from barley malt in Western countries. Traditional beverages are available in a variety of forms, including clear liquid, thick gruels or pastes and turbid liquid. The primary component is air-dried cooked rice powder and traditional starter tablets or dust are used to make a variety of beverages [66]. *Amazake*, a traditional Japanese beverage prepared from fermented rice and enjoyed in Japan for more than a millennium, is sweet, viscous and non-alcoholic. Steamed rice, rice *koji* and water are combined to make *amazake*, which is then heated for 15–18 h at a relatively high temperature (55–60 °C) (Xiong et al., 2020). A study found that consuming *amazake* before bed-time can lessen the subjective symptoms in liver cirrhosis patients. Amazake is a food that is high in vitamins and amino acids. Studies have suggested that the hepatic immune system may benefit from the branched-chain amino acids in amazake. A rising trend in today's culture is the consumption of various amazake beverages (Xiong et al., 2020).

2.3.3. *Fermented sorghum beverages*

Traditional fermented beverages made from cereal grains, particularly those made from sorghum or maize, were regarded as popular traditional drinks and are popular throughout sub-Saharan Africa and also in other sub-tropical areas. While traditional alcoholic beverages were typically sour, without any hops and also are taken in their unprocessed form, the non-alcoholic beverages were typically sweet or clear [67]. For instance, Kunu-zaki, a non-alcoholic drink, is primarily consumed in Northern Nigeria. It is regarded as one of the healthiest fermented sorghum drinks. This beverage can be made easily and inexpensively in local shops. Mahewu (*amahewu*), a sour non-alcoholic beverage, is also widely enjoyed in Africa and certain nations in the Arabian Gulf. Mahewu is typically prepared from corn, but it can also be manufactured from sorghum [68]. Sorgham exhibits high nutritional profile due to the presence of significant amounts of proteins carbohydrates, lipids and vitamins and minerals besides phytochemicals. Additionally, owing to its particular microbiota, its lactic acid bacteria-fermented goods might have probiotic properties [69].

2.3.4. Fermented millet beverages

Millets can be fermented into a wide variety of drinks utilizing microbes like yeast, acetic acid bacteria or lactic acid bacteria. The finished goods ought to be marketable to the general public and priced reasonably (Amadou., 2019). Malt or germinated millet, is frequently included as the primary ingredient in these drinks to increase the activity of amylolytic enzymes, which break down starch. Typically, yeast, as well as lactic acid bacteria are important for spontaneous fermentation. Fermented drinks made from millet are *bensaalga, burukutu, boza, bushera, fura, doro, jandh, koko, koozh, kunun-zaki, madua apong, kodo ko jaanr malwa/ajon, mangisi, oshi-kundu, ogi, oti-oka, shakparo togwa, ale*, etc. [12].

People following a gluten-free diet may benefit from substituting meals prepared from gluten-free grains such as corn, rice, millet, sorghum, amaranth, quinoa, buckwheat and wild rice [36]. Millets are gluten-free grains; therefore, they offer a lot of promise in food and beverage production, besides these could meet the rising demand for gluten-free products and would be suitable for celiac disease sufferers. The acidity of traditional millet dishes is typically comparable to that of yoghurt since they frequently undergo lactic acid fermentation. Many millet-based fermented beverages from sub-Samaritan region include tartaric acid, are very alkaline as a result of various additives and share a lot of flavour characteristics with one another. Tartaric acid acts as an acidulant and stabilizes the beverage [12]. Furthermore, standardization of additives involves the addition of water, vegetable oils, vitamins and minerals, as well as sweeteners, flavors, salts and stabilizers. Native to Nigeria, *kunun-zaki* is a fermented beverage made from millets. It has a milky,

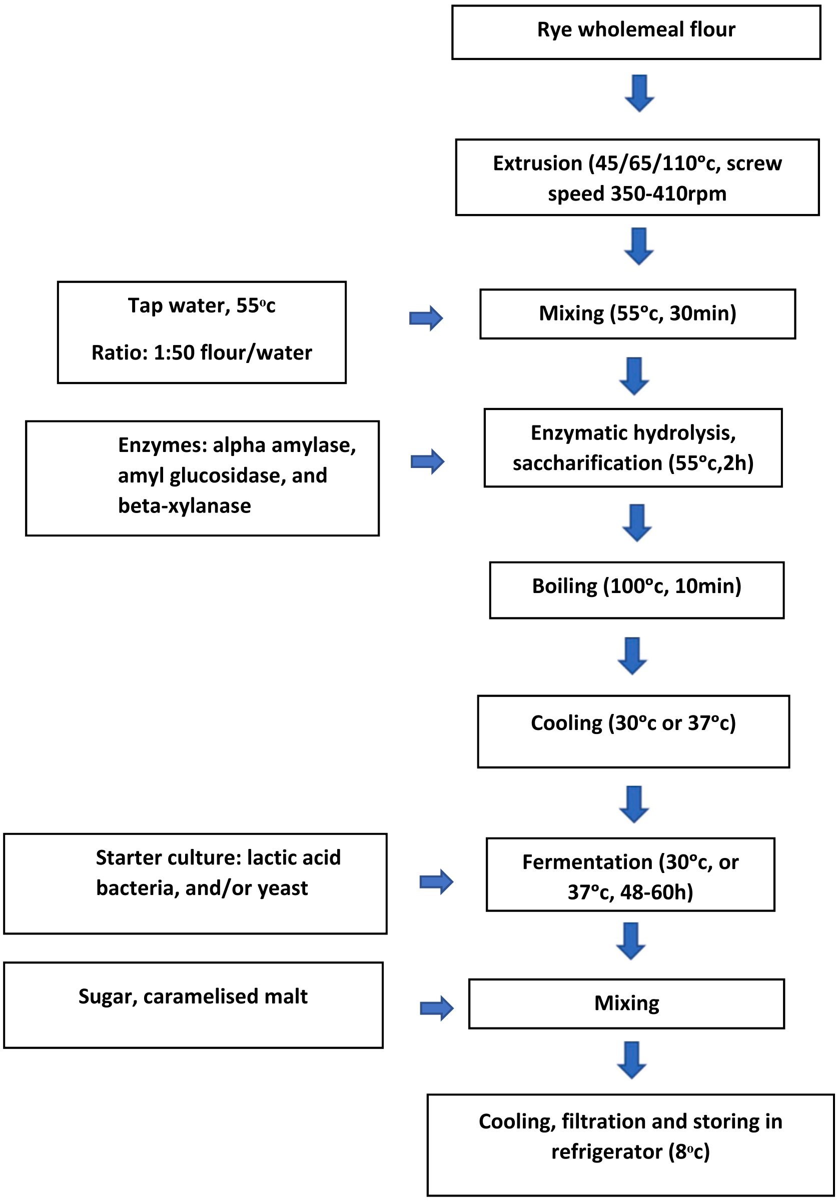

Fig. 3. Flowchart of kvass-making technique using raw material extruded wholemeal rye flour. Adapted from Ref. [57].

creamy, smooth, sweet-sour flavour. It is a cool drink, a thirst quencher and an appetiser. It is also thought to help nursing women produce more milk. *Kunun-zaki* is made via soaking, wet milling, sifting, sedimentation, cooking, mixing and finally fermentation (Xiong et al., 2020).

2.3.5. Fermented rye beverages

Common traditional drink known as *kvass* is made in Eastern and Central Europe using fermented rye malt, rye bread and rye flour. It is a naturally carbonated beverage that is suitable for all ages. It is golden-brown in color, has a sweet-and-sour flavour typical of rye bread or yeast, besides it contains yeast suspension or sediment (depending on the manufacturing process). Rye flour and rye malt are commonly used to make commercial *kvass* after they have been cooked with water. Prior to fermentation, these ingredients are combined and also subjected to saccharification (by malt enzymes) [47]. *Kvass* is regarded as a non-alcoholic beverage even though it may have trace amounts of alcohol (less than 1.5%); if the alcohol content rises above that point, the *kvass* is deemed spoilt (Xiong et al., 2020). It does not need to be pasteurized because it is a by-product of lactic-alcohol fermentation and mostly comprises lactic acid bacteria, which are beneficial microorganisms found in the human body. Fig. 3 illustrates the flowchart of *kvass*-making technique using raw material extruded whole meal rye flour. *Kvass* also possesses natural organic acids, amino acids and carbohydrates, which are crucial from a dietary and physiological perspective (Gambus et al., 2015). Lactic acid, the main metabolic product of lactic acid bacteria, has antioxidant qualities besides improving the bioavailability of calcium and other minerals. Products of yeast cells autolysis can enhance *Kvass* environment with various beneficial compounds, e.g., superoxide dismutase, able to "scavenge" excess of superoxide radicals. *Kvass* as a beverage could be thought of as a probiotic, but it must be made naturally through fermentation without any additional thermal stabilization (Gambus et al., 2015). Traditional *Kvass* has 60% more antioxidant activity than commercial *Kvass* (*in vitro*), as well as more dietary fibre and less alcohol and sugar. In Eastern and Central Europe, *Kvass* has become one of the most industrialized and well-known fermented cereal drinks due to claims about its beneficial health effects and delectable flavour (Xiong et al., 2020).

2.3.6. Potential health benefits of fermented cereal products

The main energy sources for both humans and animals are cereals and their by-products. Therefore, during the past ten years, their production has drastically increased to fulfil the demands of the rising global population [68]. Due to its ease of usage and low cost, fermentation remains the most popular biotechnological technique employed in cereal-based beverages. The opportunity for natural, functional, or non-alcoholic beverages is continuously growing due to their appealing sensory qualities and growing consumer awareness of the value of a balanced diet [63]. Non-alcoholic cereal-based fermented beverages have recently gained popularity among researchers and consumers due to their proven probiotic properties and disease prevention potential. The bioactive compounds such as proteins, essential amino acids, essential fatty acids, vitamins, phenolic compounds and others formed in the fermentative processes of cereal-derived beverages improve their nutritional properties. The microbial content and implicit improvement of gastrointestinal health are strongly related to the perceived health outcomes of fermented beverages. Furthermore, non-alcoholic fermented beverages provide a sense of well-being by stimulating the metabolic system (Schwan et al., 2019). Affordable fermented drinks are produced using conventional techniques that uphold product quality, security and hygienic standards. The fermentation process is influenced by lactic acid bacteria, which also causes a low pH that limits the growth of harmful bacteria and extends shelf-life and safety of the product. Probiotics are mixed cultures of potentially helpful bacteria that are used in traditional methods [63]. Cereal grains are high in dietary fibres like resistant starch, which can be used as fermentable substances (prebiotics) to boost the growth of probiotic microorganisms like some LAB and yeasts (Xiong et al., 2020).

The shelf life of beverages could be extended by fermentation by increasing the acidity and preventing some spoilage and unfavourable microbes. Various volatile substances, including organic acids, are produced during cereal fermentations such as butyric or lactic acids, aldehydes, ketones and alcohols (like ethanol), resulting in the complex flavour fusion of products (Xiong et al., 2020).

Foods that have undergone fermentation are linked to a special type of microflora that improves their nutritional value by adding nutrients including proteins, vitamins, vital amino acids and fatty acids [64]. As described already above, the bioactive compounds included in cereals are directly related to beneficial health effects of fermented cereal beverages. However, three-quarters of the world's population lacks access to basic food and is undernourished. In this way, issues with the global diet can be solved by fermented food products. Due to the regional differences in weather circumstances, cultural and socio-economic factors, taste preferences, raw material availability and new technical advancements, cereal based fermented beverages are frequently distinctive and unique. To combat food and nutrition insecurity, several types of fermented food products are made based on the raw materials that are accessible (Anal. 2019). There is a rapidly expanding trend globally toward probiotic-containing foods and beverages, hence it is probable that demand for fermented cereal beverages will rise [70].

3. Safety issues

When regularly eaten as part of a diverse diet, cereal-based functional drinks, whether produced industrially or traditionally, have the potential to benefit health beyond basic nutrition. This suggests that these products ought to provide therapeutic benefits when regularly consumed in conjunction with a diversified diet, provided that the primary nutrients are extracted in a standardized manner and dosage [63]. The majority of cereals are naturally fermented by a combination of yeast, bacterial and fungal cultures. During fermentation, some bacteria may function in parallel while others behave sequentially with changing dominant flora during fermentation. The difficulty, however, is the fermentation's often unregulated nature, which causes safety problems, as well as the lack of uniformity in the procedures used, which further increases safety concerns. Temperature, time and moisture for soaking and germination vary both within and between processors. Additionally, the grains may become infected by fungi during soaking and germination, which could result in the production of mycotoxins.

It is feasible to extend shelf life by co-incubating probiotic cultures, as demonstrated in the production of various cereal-based fermented drinks, or to market to a group of customers searching for healthy and functional foods. The dominant microorganisms involved in the fermentation of cereal-based beverages have no reported health risk to human life (Daniel et al., 2022). Most of the bacteria used as probiotics, such as Lactobacillus (LAB) and Bifidobacterium, are of human or animal origin and usually regarded as safe (GRAS). Nonetheless, it was reported that a few highly dubious cases of endocarditis were associated to certain strains of *Enterococcus faecium*, *E. faecalis* and *Lb. rhamnosus* [71]. Probiotic species or genera including *Escherichia coli, Nissle, Saccharomyces boulardii*, *Streptococcus thermophilus*, *Enterococcus francium, Propionibacterium, Pediococcus* and are generally recognized as safe. On that basis LAB, but not enterococci, are generally regarded as safe and can be used in the preparation of cereal-based probiotic beverages. Recent research has shown that the Boza strain *Enterococcus faecium YT52*, because it fights dangerous pathogens like *Listeria monocytogenes* and *Bacillus cereus*, the enterocin-producing *E. faecium YT52 strain*, offers no risk to consumer health and can be utilized as a starter or co-starter culture to increase the food safety of fermented goods [72]. However, the technologies used to prepare fermented foods still require extensive research to ensure food safety, including cautious beginning culture selection and in-depth examination of the specific bacteria. For instance, *Lactobacillus* and *Bifidobacterium*, other genera such as Enterococcus have safety concerns as some of the species are pathogenic [71]. Rethinking the technological processes utilized to create diverse cereal-based fermented beverages can also enhance their functionality and overall medicinal and nutritional benefits. Functional cereal fermented beverages are gaining popularity as healthy substitutes for consumers who are lactose intolerant or who avoid particular allergens. In the manufacturing of traditional beverages, where the fermentation process is spontaneous, maintaining product safety, however challenging at times, is an essential step. Therefore, the positive effects of microbe management are reflected in the safety of the product, extended shelf life, improved nutrient contents and availability, palatability and improved sensory characteristics.

4. Summary and future perspectives

The role of cereals and cereal products with regard to the rates of consumption and nutritional value is extensively covered in scientific literature. Different cereals contain vitamins and minerals, folate, thiamine, iron, niacin, manganese, dietary fibre, as well as zinc. Consuming nutrient-rich meals that contain protein, lipids, B-complex vitamins, vitamin E and minerals is associated with eating whole grain cereals, which are also linked to better diet quality. The majority of these nutrients are concentrated in the bran part. However, because it commonly causes processing issues, bran is typically eliminated during food processing. Despite this, cereal bran could be utilized to make functional foods or beverages or as a fortifying element that can be added to foods or beverages. It is a highly useful health-functional substance.

Recently introduced into the market, cereal grain-based milk is a useful beverage that is gaining popularity across the globe. Cereal milk differs from cow milk in that it is hypoallergenic, lactose-free and also includes bioactive components with health-promoting characteristics. It is also more affordable and eco-friendlier. It is possible to consider plant-based water-soluble extract origin as an alternative to cow milk, but it must be fortified in order to enhance its nutritional aspects and composition and make it comparable to those of cow milk. This fortification could be carried either by mixing two or more plant-based milk substitutes or by adding additives. It is also crucial to be aware about potential means of enhancing the nutritional qualities through processing. Additionally, it is important to make sure that the general public enjoys and accepts this milk substitute.

For the past few years, tea made from cereal grains has drawn the most significant interest. While some of the elements contributing to the unfavourable effects of cereal-based tea on health aspects have been identified, others are yet unclear. It has been proven that the health effects of tea beverages prepared from cereals are directly attributed to the bioactive phytochemicals in the beverages. One of the enticing qualities of grain tea is its distinctive roasted or malty scent. However, further research is required to be conducted to identify the volatile components that impart specific odours in these types of cereal beverages. Finding out how to change the processing variables to get the right phenolic, as well as functional profile with premium tea quality would require more research.

Fermented non-alcoholic beverages made from cereal grains come in a wide range of goods that are sold all over the world. Most fermented grain beverages are still produced locally in small facilities and at home. Fermentation gives cereal drinks enhanced flavour, nutritional value, safety and also health-promoting characteristics. Poor and inconsistent preparation of these traditional fermented grain beverages, as well as poor hygiene standards used throughout production, raises questions about the microbiological safety of food. Additional research may reveal the essential characteristics and bacterial/fungal species linked to premium flavour and scent. However, the beneficial health effects of these historically fermented cereal beverages have not been well explored, necessitating future research to generate conclusive data. The fermented cereal beverages are possible probiotic beverages and have been called functional foods.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

No data was used for the research described in the article.

Declaration of competing interest

The authors confirm no conflict of interest.

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