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Chemistry

Cereal and oat-based beverages as a functional alternative for human consumption

Bebidas à base de cereais e aveia como alternativa funcional para consumo humano

Dannyele Fernanda Souza Oliveira[I], **Luciane Maria Colla**[I]

[I] Universidade de Passo Fundo, Passo Fundo, RS, Brasil

ABSTRACT

The growth of plant-based beverages is driven by the demand for healthy and sustainable alternatives, with a focus on their nutritional advantages and lower environmental impact. The consumption of cereals offers various health benefits, and oats, with their beta-glucan fibers, are especially effective in reducing cholesterol, making them an excellent option for nutritious plant-based beverages. This literature review aims to highlight the nutritional and technological advancements related to oats as a viable option for plant-based beverages. A search was conducted in Scopus database using the keywords “beverage” and “functional” and “cereals”, and “Beverage” and “oat”, during the period from 2019 to 2024, with the goal of identifying key nutritional and technological advancements. Oats stand out as an excellent substrate for microorganism growth, making them a valuable raw material for beverage development. Recent advancements in the field include the use of spectroscopy and neural networks for precise fermentation monitoring, high-intensity application to enhance the development of probiotic beverages, as well as the stabilization of emulsions in oat-based products. However, challenges remain, such as the need to optimize the appearance, nutritional profile, and sanitary quality of traditional beverages. Despite these challenges, the use of oats for beverage production is increasingly promising, emerging as a healthy and innovative option for consumption.

Keywords: Cereal beverages; Oats; Water-soluble extracts

RESUMO

O crescimento de bebidas vegetais é impulsionado pela demanda por alternativas saudáveis e sustentáveis, com foco em suas vantagens nutricionais e menor impacto ambiental. O consumo de cereais oferece vários benefícios à saúde, e a aveia, com suas fibras beta-glucanas, é especialmente eficaz na redução do colesterol, tornando-a uma excelente opção para bebidas vegetais nutritivas.

Esta revisão de literatura visa destacar os avanços nutricionais e tecnológicos relacionados à aveia como uma opção viável para bebidas vegetais. Foi realizada uma busca no banco de dados Scopus usando as palavras-chave “bebida” e “funcional” e “cereais”, e “bebida” e “aveia”, durante o período de 2019 a 2024 com o objetivo de identificar os principais avanços nutricionais e tecnológicos. A aveia se destaca como um excelente substrato para o crescimento de microrganismos, tornando-a uma valiosa matéria-prima para o desenvolvimento de bebidas. Avanços recentes no campo incluem o uso de espectroscopia e redes neurais para monitoramento preciso da fermentação, aplicação de alta intensidade para aprimorar o desenvolvimento de bebidas probióticas e a estabilização de emulsões em produtos à base de aveia. No entanto, desafios permanecem, como a necessidade de otimizar a aparência, o perfil nutricional e a qualidade sanitária de bebidas tradicionais. Apesar desses desafios, o uso de aveia para produção de bebidas é cada vez mais promissor, surgindo como uma opção saudável e inovadora para consumo.

Palavras-chave: Bebidas de cereais; Aveia; Extratos solúveis em água

1 INTRODUCTION

The modern food industry has produced high-calorie, low-nutrient options, largely influenced by consumer choices and purchasing habits (Heo et al., 2020; Masiá et al., 2021). Based on this, there is a need to implement food reformulations and development strategies to improve dietary and nutritional outcomes (Anitha Sri et al., 2022; Yang et al., 2023). Among foods, functional beverages stand out as one of those options that provide nutrients such as vitamins, minerals, fatty acids, antioxidants, and other biologically active substances (Mohammadi et al., 2021; Patra et al., 2023; Pérez-Rodríguez et al., 2023; Rincon et al., 2020).

Plant-based beverages are produced from cereals, pseudocereals, oilseeds, seeds, and legumes. Preparation begins with soaking the base ingredient in water for several hours. The mixture is then strained to obtain the beverage (Herrera-Ponce et al., 2022; Mohammadi et al., 2021; Patra et al., 2023; Rincon et al., 2020). Plant-based beverages can be considered an alternative for a percentage of the population that cannot consume certain types of foods due to lactose intolerance or milk allergy (Bocker & Silva, 2022; Ziarno & Cichońska, 2021).

Among the cereals used to produce plant-based beverages, oats (*Avena sativa*) stand out as a remarkably nutritious whole grain (Stewart & Mcdougall,

2014), being considered a source of proteins and amino acids (Kumar et al., 2021; Ziarno & Cichońska, 2021), beyond of starch, moderate levels of lipids, and soluble fibers, including β-glucan, which provides functional claims (Dąbrowski et al., 2022; Malafronte et al., 2023). This makes it a subject of interest for fermentation by lactic acid bacteria, which transform oat components into healthier compounds (Algonaiman et al., 2022; Ferreira et al., 2022; He et al., 2022)

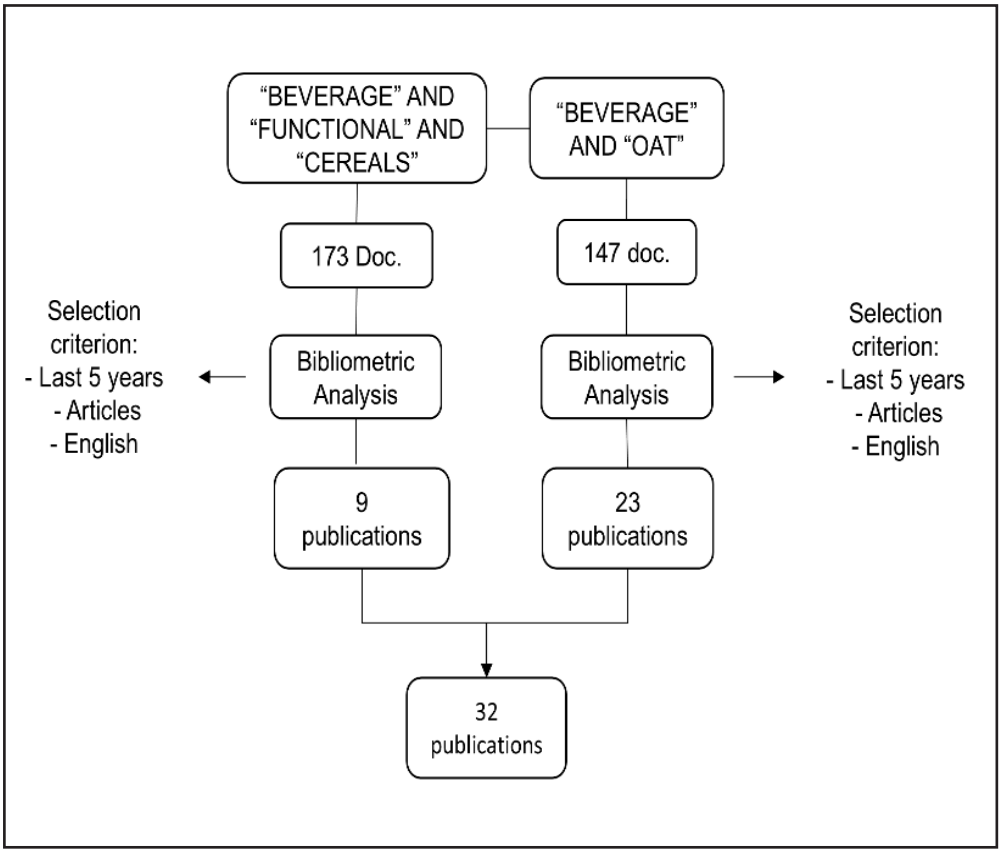
In this context, the growing demand for plant-based beverages highlights the need for updated scientific syntheses capable of integrating nutritional, technological, and functional aspects of cereal-derived products. Although several studies have advanced in the characterization of oat-based beverages, there is still a lack of comprehensive discussion connecting grain composition, fermentation dynamics, ingredient functionality, and technological innovations that support industrial development. Therefore, this review aims to bridge these knowledge gaps by summarizing recent progress in the nutritional profile of oats, their technological applications in beverage formulations, and the current challenges and opportunities shaping this emerging category of functional beverages.

2 METHODS OF BIBLIOMETRIC REVIEW

The search of articles was accomplished in the Scopus database. Data were analyzed based on the limitation of the year of publication, title, and abstract, as described in Figure 1. In the first stage, a search was conducted using the keywords ‘beverage’, ‘functional’, and ‘cereals’, resulting in 173 documents. In the subsequent stage, the search criteria were the words ‘Beverage’ and ‘oat’, resulting in 147 articles. Inclusion criteria were restricted to English-language articles relevant to the study’s theme published within the last five years, resulting in 32 publications, as shown in Figure 1. The bibliometrics aimed to select the most recent studies on beverages developed from oats, as well as their methodological and nutritional advances.

The Scopus database reveals that India leads in the number of scientific papers published on cereals and plant-based beverages. Extensive evaluations are being conducted on the quality of beverages made from millet, rice and other cereals. When it comes to oat-based beverages, however, the United States stands out as the leading country in terms of published research.

Figure 1 – Flowchart of bibliometric analysis

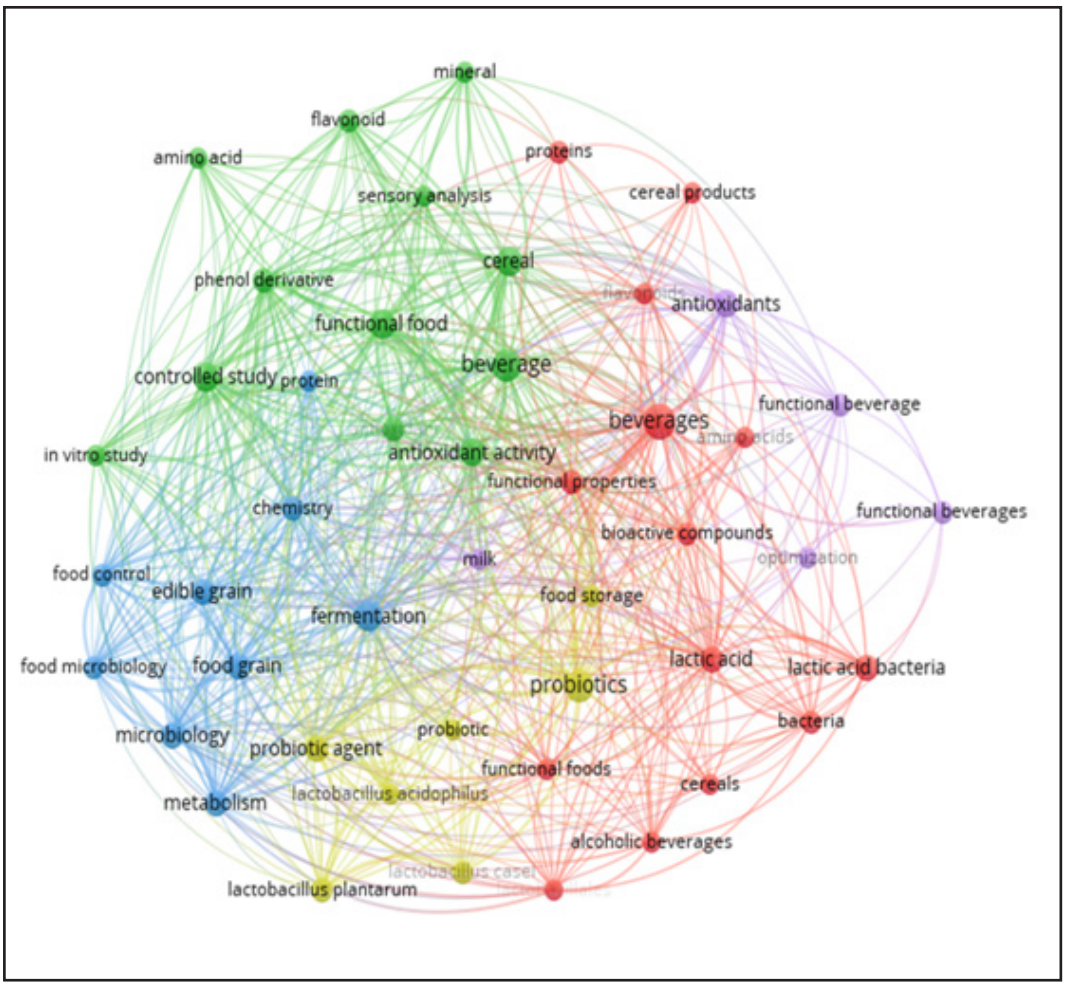


Source: Authors (2024)

The cluster image (see Figure 2) represents different themes related to food and beverages. The yellow cluster focuses on the main bacteria used in fermentation, such as *Lactobacillus acidophilus* and probiotic agents essential for beverage formulation. The green cluster addresses functional foods, highlighting antioxidant activity, functional properties, milk, and food storage. The red cluster focuses on the functionality of beverages, emphasizing antioxidants, bioactive compounds, and alcoholic beverages,

which are crucial for digestive health and combating oxidative stress. The blue cluster explores fermented beverages, examining metabolism, food microbiology, cholesterol impact, and the role of bacteria in the fermentation process.

Figure 2 – Map of the articles obtained with the keywords “Beverage” and “probiotic” and “cereals”

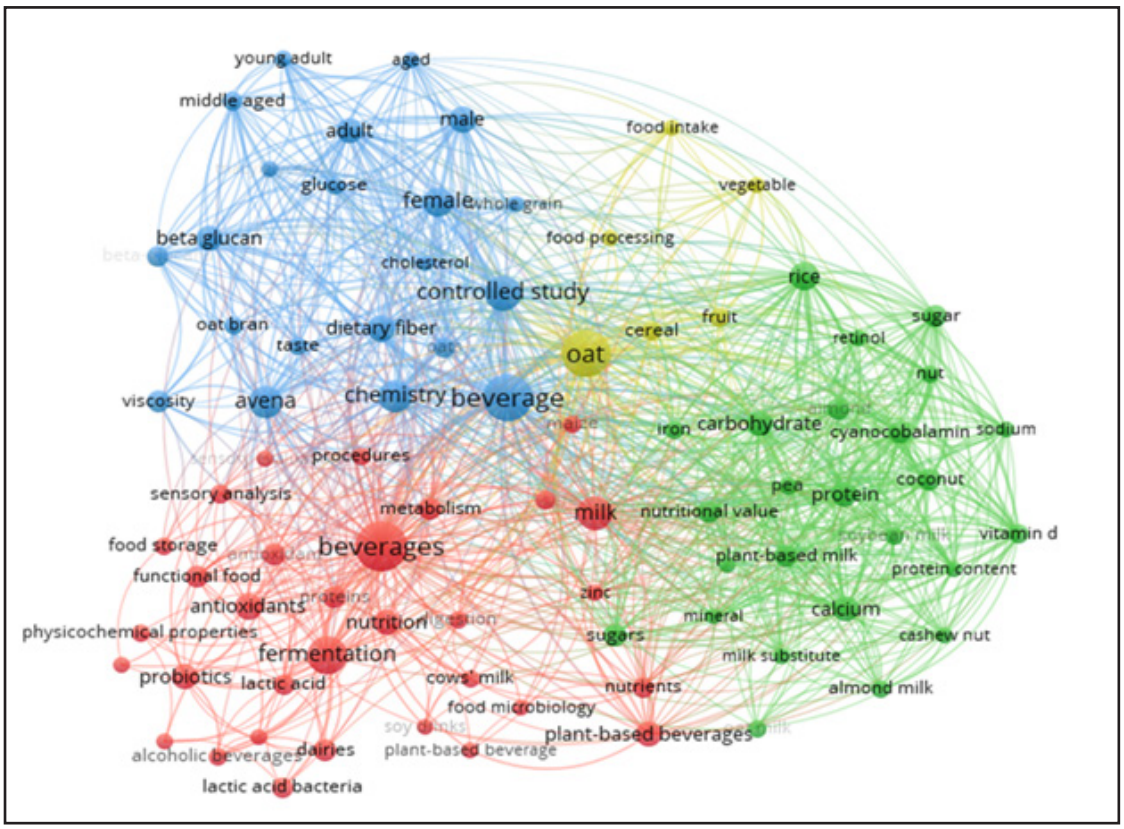


Source: Graphs generated by VOSviewer (2024)

Figure 3 presents five main clusters. The first cluster, in blue, focuses on studies about humans, food intake, with an emphasis on adults and foods like oats. The second cluster, in red, addresses fermentation, antioxidants, and probiotics, highlighting fermented beverages and sensory properties. The third cluster, in green, deals with plant-based beverages, such as almond and coconut milk, exploring their nutritional composition. The fourth cluster, in yellow, involves cereal-based foods, especially rice

and oats. The fifth cluster, in purple, focuses on the physicochemical properties of beverages, such as viscosity and stability.

Figure 3 – Map of the articles obtained with the keywords “Beverage” and “oat”



Source: Graphs generated by VOSviewer (2024)

These clusters provide a comprehensive framework for the systematic review, which will discuss the main topics throughout the text, such as the nutritional composition of the grains used for beverage development, as well as the physicochemical characteristics of the beverages themselves.

3 OATS AND THEIR NUTRICIONAL COMPOSITION

3.1 Oats and their nutricional composition

In Brazil, white or yellow oats (*Avena sativa L.*) are grown for human consumption, while black oats (*Avena strigosa Schreb* and *Avena brevis Roth*) are used as fodder for animals and soil quality improvement (Brasil, 2022).

Oats are a highly valued cereal, known for their mild flavor and nutritional value, making them a promising choice for the development of food and beverages. When subjected to specific processes, such as fermentation, modifications in their organic profiles may occur, potentially enhancing their nutritional qualities (Küçükgöz et al., 2024).

On the market, different types of oats are available, mainly distinguished by the manufacturing process and degree of refinement. This cereal is widely recognized for being an excellent source of proteins and for containing various beneficial minerals, such as iron, calcium, potassium, magnesium, copper, zinc, silicon, and selenium. Additionally, oats are rich in a variety of vitamins (El-mascarado et al., 2023).

Oat-based beverages exhibit antidiabetic and hypolipidemic properties, in addition to contributing to intestinal health regulation, promoting metabolic health, and reducing the risk of cardiovascular diseases (Chen et al., 2020). Plant-based beverages can be made from a single cereal, such as oats, or from a combination of different cereals. Moreover, it is common to enrich these beverages to increase their nutritional value and improve other characteristics, such as flavor and viscosity (Horlacher et al., 2024).

3.1.1 Carbohydrates, fiber

Beverages made from cereals typically contain between 60% and 75% starch in their composition. Starch represents the main form of energy storage in cereals. For instance, oat-based beverages contain a significant amount of carbohydrates, which is relevant to their nutritional Properties (Moore et al., 2023).

Cereals such as wheat, rye, and oats contain starch in their endosperm, which consists of amylose and amylopectin that gelatinize differently depending on their ratio. Moreover, whole grains like rye and oats are high in fiber. Thermal processing of grains causes starch granules to swell and release macromolecules from the endosperm cell wall, contributing to the health benefits of consuming whole grains (Malafronte et al., 2023).

In the production of oat-based beverages, carbohydrates are the primary nutrient. The presence of sugars is advantageous for fermentation, as these simple

sugars serve as a readily usable carbon source for microorganisms during the process. This not only contributes to the quality of the beverage but also to its sensory characteristics (Dąbrowski et al., 2022).

Fermentation induces changes in the carbohydrate content, such as fructose and sucrose, which can directly influence the sensory characteristics of the beverage. These changes can reduce sweetness and impact the final product's consistency, thereby altering consumer perception (Ziarno et al., 2024).

Studies with fermented oats have shown complete metabolism of glucose, while fructose and disaccharides exhibited significant reductions in oat beverages, demonstrating the efficiency of carbohydrate metabolism (Küçükgöz et al. 2024).

Among the carbohydrates present in oats, β-glucans stand out as soluble fibers that provide health benefits, such as lowering cholesterol and blood glucose levels. In oat-based beverages, they function as prebiotics during fermentation, playing a crucial role in pH modulation, increasing lactic acid production, and contributing to the characteristic flavor of the fermented drink (Yu et al., 2023).

The stability of β-glucans during fermentation is essential for the functionality of the fermented beverage, as they promote microorganism growth and the production of bioactive compounds beneficial for intestinal health (Chen et al. 2020). However, studies show that whole oat bran is unsuitable for acidified products, leading to undesirable texture and appearance in beverages. Replacing bran with whole oats affects beverage stability due to the loss of the β-glucan network, which is crucial for maintaining viscosity and preventing phase separation (Patra et al., 2022).

Oats are highly suitable as a substrate for the fermentation of various microorganisms, such as *L. plantarum*, *L. casei*, *L. acidophilus*, *L. bulgaricus*, and *S. thermophilus*. Within this range of microorganisms, *L. acidophilus* stands out for its efficacy in bacterial development. Regarding β-glucans, it is noteworthy that the microorganism *S. thermophilus* retains the highest concentration after a 24-hour

fermentation period, making oats an excellent medium for promoting the growth of these beneficial microorganisms (He et al., 2022).

Additionally, a pioneering study analyzed both the food matrix and the fermentation process concerning the inhibitory activity of angiotensin-converting enzyme. This study also considered the release of β-glucans, employing a method that investigates the concentration of proteins and peptides. As a result of this process, β-glucan was made available for fermentation by the gut microflora (He et al., 2022).

In another study, the use of resistant dextrins derived from sorghum and oats was discussed. These dextrins showed properties that can benefit gut health, stimulating the growth of beneficial bacteria such as *Lactiplantibacillus plantarum, L. acidophilus*, and *L. delbrueckii*. These findings suggest that resistant dextrins have potential as ingredients in beverages and other foods, especially as soluble fibers and prebiotics (Chen et al., 2022).

3.1.2 Proteins

Oats have an excellent amount of protein, estimated to be between 15% and 20% of their composition. This ratio is notably higher than that found in other cereal varieties (Kumar et al., 2021). Among plant-based beverages, oat-based drinks stand out for their high protein content and properties that bring them closer to the nutritional profile of cow's milk, particularly concerning protein quality (Tangyu et al., 2023).

When subjected to fermentation by lactic acid bacteria, oat beverages can enhance both the flavor and digestibility of the proteins present, expanding consumer Options (Tangyu et al., 2023). Although oat beverages have lower digestibility compared to others, such as soy milk, they still offer significant nutritional benefits. Oats are a good source of fibers and bioactive compounds, which can complement their role in the diet, despite the lower protein digestibility (Khamzaeva et al., 2024).

Oat beverages, when combined with lupin and nettle leaves, promote the breakdown of complex proteins into more soluble forms, significantly increasing the

protein content. This combination of cereals and legumes enhances the nutritional value and improves protein quality, making the beverage more complete and accessible (Alemayehu et al., 2022).

The use of technologies such as pre-treatment in the production of oat beverages supports the recovery of nutrients that may be lost during processing. For example, the application of ultrasound allows for the recovery of up to 39% of fibers like β-glucan, as well as partial breakdown of the protein structure (Kwok et al., 2024).

Another relevant factor is the flavor profile of the beverages, which is directly related to the amino acids present. The choice of specific microorganism strains influences the creamy notes and buttery flavor, enhancing the sensory characteristics of the beverage (Tangyu et al., 2023).

The amount and type of fatty acids present in fermented beverages, such as oats, are influenced by varying factors, including the type of beverage and the ingredients used in fermentation. In the case of oats, it is common to find fatty acids with 18-carbon chains, as well as concentrations of oleic acid and linoleic acid, both of which are unsaturated in nature. These fatty acids are important in determining the lipid profile of the beverage, influencing its sensory characteristics and nutritional value (Dąbrowski et al., 2022).

3.1.3 Phenolic compounds

Antioxidants can be classified into two categories: dietary antioxidants and natural antioxidants. Dietary antioxidants, such as vitamins C and E, are commonly obtained from processed foods and supplements. On the other hand, natural antioxidants are intrinsically found in foods such as fruits, vegetables, and beverages, without the need for additional processing (Comert & Vural, 2022).

Cereal grains contain insoluble phenolic compounds with antioxidant activity, with oats being particularly rich, reaching a proportion of 82%. These compounds are strongly bound to the structural elements of grains, such as the cell wall and cellulose

(Comert; Gokmen, 2022). Oats contain bioactive properties such as polyphenols and flavonoids. These characteristics make it a highly promising substrate for fermentation (He et al., 2022). Oats help lower cholesterol levels, partly due to the flavonoids in their whole form. These compounds act as antihyperlipidemic agents, supporting cardiovascular health (Duan et al., 2021).

The antioxidant content in a beverage can vary based on the presence of these compounds and added supplements. In an oat-based beverage with fermented sunflower seeds and almonds, higher antioxidant activity was observed with the addition of propolis extract (Ferreira et al., 2023).

Studies with oat flour fermented by lactic acid bacteria show its potential for functional beverages. Fermentation significantly increased free phenolic compounds and the inhibitory activity of angiotensin-converting enzyme (ACE), with improvements of up to six times compared to the non-fermented control (Moiseenko et al., 2024). Additionally, the combination of oats with the fermentation process using lactic acid bacteria demonstrates an increase in the bio accessibility of specific amino acids, vitamins, and polyphenols (Bocchi et al., 2021).

Studies comparing homemade oat beverages with commercial ones indicate that fermentation released bioactive compounds, such as polyphenols, and improved nutrient bioavailability. After 24 hours of fermentation, greater stability in antioxidant activity was observed in homemade products compared to commercial ones (Łopusiewicz, 2024).

The combination of oats with another ingredient, such as honey, develops an increase in the main phenolic compounds present in methanolic extracts. These compounds include gallic acid, catechin, vanillic acid, among others (Chen et al., 2020).

In addition to lactic acid bacteria, it is also possible to use yeast in beverage development. The yeasts *Saccharomyces cerevisiae* and *Pichia cecembensis* were isolated and tested for their functionality and safety as probiotics in a traditional Ethiopian fermented beverage. The results demonstrated that these yeasts were able to reduce

cholesterol levels by 82% to 89%. Additionally, they showed remarkable antioxidant activity and the ability to survive in the intestinal environment. However, it is important to note that these yeasts exhibited resistance in susceptibility tests to antibiotics (Gebre et al., 2023).

3.2 Fermented Beverages form cereals

Fermented plant-based beverages are known for enhancing essential characteristics such as flavor, texture, and nutritional value. These benefits are attributed to the presence of probiotic strains and bioactive compounds resulting from the fermentation process, which also contribute to health promotion (Marchwińska et al., 2023).

These beverages are produced by homogenizing extracts from cereals, pseudocereals, seeds, and other plants. They form a colloidal dispersion where proteins, carbohydrates, lipids, and fibers are suspended in an aqueous matrix, ensuring stability and uniform texture. As alternatives to animal-derived milk, they are popular in vegan and lactose-free diets (Bocker; Silva, 2022).

Recent research has explored the use of cereals, such as malted barley, as prebiotic sources for fermentation with *Saccharomyces* yeasts. These formulations, made from germinated malt and water, were processed with various flavorings like nuts and strawberry. Results showed promising gastrointestinal transit resistance, with a sensory preference for nut-flavored beverages (Zommiti et al., 2020).

The use of germinated cereals has also been studied by Aparicio-García et al., (2021), revealing that blends of cereals and legumes, such as chickpeas in their flour, malted and roasted forms, offer high nutritional value. These blends resulted in a beverage with a protein content of 21.39% and an in vitro digestibility of about 90.40%. Adding salt and brown sugar increased acceptability, with roasted flour formulation performing best (Kaur & Prasad, 2024).

In addition to these approaches, incorporating design models to optimize the composition of multigrain products is being employed to further improve beverage

nutrition (Fernandes et al., 2019). Another study focused on germinated buckwheat and amaranth. Oats were added during grinding, followed by mixing with potable water. This liquid was then combined with skim milk and sugar, resulting in a beverage high in dietary fibers and antioxidants (Habib et al., 2023).

We will continue to highlight the main cereals that emerged in the bibliometric review. Table 1 shows the cereals, microorganisms and fermented beverages found in several countries, as well as their health benefits.

The incorporation of milk into plant-based beverages has also been explored in various studies. For example, a fermented cereal whey beverage made from germinated millet, beans, and skim milk powder demonstrated commercial potential. Its shelf life was enhanced through the use of the preservative nisin, improving storage conditions (Rani et al., 2024).

Innovative approaches include using co-cultures composed of an exopolysaccharide-producing strain (*Weissella Confusa*) and a probiotic strain (*L. plantarum*) to create a synbiotic product. This method demonstrated highly satisfactory results, yielding a fermented beverage with considerable nutrient density and positive acceptance (Vila-Real et al., 2022). Among cereals used in beverage development, rice also stands out. *Neeragaram*, a traditional rice-based beverage, involves cooking rice with spices like green chili, scallions, curry leaves, and coriander before fermentation (Anitha Sri et al., 2022). Similarly, *Boza*, a traditional drink made from corn semolina and wheat flour, is cooked together, mixed with water, sugar, and bacterial cultures to start fermentation, resulting in a flavorful and nutrient-rich Beverage (Arslan-tontul & Erbas, 2019).

Other traditional fermented cereals include beverages like *Boza*. Traditional Kyrgyz beverages such as *Bozo*, *Maksym*, and *Zharma* are made from ground cereals like barley, millet, and corn. These are fermented with lactic acid bacteria or yeast, resulting in either low-alcohol or non-alcoholic drinks. Their production reflects Kyrgyz cultural traditions, preserving ancient practices and showcasing the region's diverse

beverage options (Smanalieva et al., 2022). Additionally, beer wort can be combined with rooibos tea infusions and fermented with balsa and yeast, resulting in a beverage with a balanced nutritional profile, a glycemic index around 80%, and high antioxidant capacity (Agarbati et al., 2024).

Studies have also explored both raw and parboiled rice, which, after cooking in water, received added spices. Analysis of the physical and nutritional characteristics indicated that the resulting beverage, *neeragaram*, is a healthy and nutritious alternative (Anitha Sri et al., 2022).

Table 1 – Cereals, pseudocereals and grains used for the development of fermented beverages

(To be continued...)

Cereal/ Pseudocereal	Country	Microorganisms/ enzymes	Methodology	Properties	Reference
Rice	India	Natural fermentation	Raw and parboiled rice (both polished and unpolished) was used. The rice was cooked, fermented with spices at 30°C, and then dehulled.	The beverage made with raw, unpolished rice showed the best nutritional quality and highest acceptability, with fermentation being essential for this performance.	Anitha Sri., (2022)
Beer wort and rooibos	Italy	*Lachancea thermotolerans, Kazachstania*	The preparation involved 60% of the non-hopped mash and 40% of red rooibos infusion. Nine yeast strains were inoculated and fermented at 25°C, with CO2 production and cell viability monitored.	The results showed that the beverage had increased phenolic compounds, enhanced antioxidant capacity, and a balanced glycemic index.	Agarbati et al. (2024)

Table 1 – Cereals, pseudocereals and grains used for the development of fermented beverages

(To be continued...)

Cereal/ Pseudocereal	Country	Microorganisms/ enzymes	Methodology	Properties	Reference
Wheat, sorghum or corn	Ethiopia	*Pediococcus (acidilactici)* yeasts *Saccharomyces cerevisiae*	The methodology involved collecting "borde" samples, isolating bacteria and yeasts, and evaluating their probiotic properties under simulated gastrointestinal conditions.	The bacterial strains demonstrated greater cholesterol-lowering potential than the yeasts, along with high antioxidant activity and good survival under simulated intestinal conditions.	Gebre, et al., (2023)
Corn semolina, wheat semolina, and chickpea flour	Türkiye	*L. acidophilus, Bifidobacterium, Saccharomyces boulardii*	The boza was made from a mixture of corn and wheat semolina, enriched with gluten, zein, and chickpea flour. After cooking and adding sugar, the mixture was fermented with bacteria at 37°C for 24 hours and then analyzed.	The addition of chickpea significantly increased probiotic counts in the beverage, while gluten quadrupled the protein content. A total of 36 volatile compounds, including fatty acids, were identified.	Arslan-Tontula; Erbasb, (2019).
Oats and buckwheat	Poland	*L. rhamnosus e L. johnsonii*	The cereals were soaked, mixed, strained, filtered, and pasteurized at 72°C for 15 minutes. After cooling, probiotic strains were added for fermentation at 37°C for 5 hours. The fermented beverages were then stored at 4°C.	The results after fermentation indicated complete glucose metabolism, reduced fructose and disaccharides, increased acetic acid, and decreased malic acid.	Küçükgöz et al. (2024).

Table 1 – Cereals, pseudocereals and grains used for the development of fermented beverages

(To be continued...)

Cereal/ Pseudocereal	Country	Microorganisms/ enzymes	Methodology	Properties	Reference
Corn, rye, alfalfa sprouts	Iran	*L. casei, L. plantarum*	Seeds were soaked, germinated, and the sprouts were crushed and pasteurized. Bacteria, inulin, and oligofructose were added, and the mixture was incubated at 30°C until reaching pH 4.8, then stored at 4°C for analysis.	The beverage showed good bacterial viability, with *L. casei* maintaining effectiveness for up to 28 days and 55% of strains surviving simulated gastrointestinal conditions. The product was also well accepted sensorially.	
Ginseng, poria cocos, rice beans, tangerine peel and cassia	China	*L. rhamnosus,L. plantarum e L. fermentum.*	The methodology involves mixing the ingredients, soaking, heating, and cooling them before centrifugation. After these steps, lactic acid bacteria are added, and fermentation takes place at 37°C for 72 hours.	The beverage showed a significant increase in antioxidant capacity after fermentation with *L. fermentum*, developing a more pleasant flavor by eliminating undesirable tastes and enhancing fruity aromas and acidity.	Yan et al., (2023)
Millet and moth beans	India	*L. lactis ssp. Lactis, L.s lactis ssp. cremoris e L. lactis ssp. lactis biovar. diactetylacti*	Whey, made from milk and cream, was mixed with sprouted millet and moth bean paste. Treatments of thermization, nisin, or both were applied, while the control was untreated. The beverages were packaged and stored at 5°C.	The combination of nisin and thermization ensured sample stability for 21 days, demonstrating its effectiveness in extending the shelf life of cereal-based fermented whey beverages.	Rani et al. (2024).

Table 1 – Cereals, pseudocereals and grains used for the development of fermented beverages

(Conclusion)

Cereal/ Pseudocereal	Country	Microorganisms/ enzymes	Methodology	Properties	Reference
Germinated chickpea, roasted, and roasted barley	India	-	The blend was made from germinated chickpea flour, roasted chickpea, roasted barley, and methionine. The seeds were soaked, germinated, roasted, and ground, then mixed to form the base of the beverages.	The blends exhibited improved protein quality, good digestibility, and a balanced amino acid profile. The addition of salt, spices, and brown sugar enhanced the palatability.	Kaur; Prasad, (2024)
Oats, barley, buckwheat, red rice.	India	Alpha-amylase enzyme	The grains are subjected to roasting, cooking, grinding, and filtration. Then, the enzyme is added, followed by pasteurization and storage at 4ºC.	The beverage had a low glycemic index, with enzyme and additives improving viscosity and sensory quality.	Fernandes; Sonawane; Arya, (2019)
Oat and malt	India	-	The sprouted grains were dried, ground, and mixed in different proportions with water to create a malted beverage.	The beverage showed increased dietary fiber, including β-glucan, and improved nutritional composition with higher levels of minerals and antioxidants.	Habib et al. (2023)

Source: Authors (2024)

Compared with commonly employed substrates such as rice, soy, and almond, oats offer several technological and nutritional advantages for beverage development. Their naturally high β-glucan content improves viscosity, enhances emulsion stability, and provides recognized health benefits associated with cholesterol reduction and glycemic control. Additionally, oats exhibit superior fermentability, supporting the growth of lactic acid bacteria more efficiently than rice or almond matrices, which often require added sugars or stabilizers. Oat-based beverages also present a mild

sensory profile, reducing the need for flavor masking and promoting better consumer acceptance. These combined features make oats a highly attractive and competitive substrate relative to traditional plant-based beverage ingredients.

4 CURRENT CHALLENGES AND FUTURE PERSPERCTIVES

The constant quest for improvements in food quality has led to the exploration of various technologies and techniques. One notable advancement is the application of Two-Dimensional Fluorescence Spectroscopy (2D) combined with Partial Least Squares Regression (PLSR) and Artificial Neural Networks (ANN). These technologies were used to quantify cell growth and the concentrations of lactic acid and glucose during the fermentation process in real-time. The results showed promising prospects regarding the viability of these tools as monitoring instruments (Alemneh et al., 2022).

Another innovative approach involves the use of high-intensity ultrasound (40kHz, 11W/cm^2) combined with whey and oat formulations to develop probiotic beverages. A 3-minute exposure period led to higher levels of growth of *Lactobacillus casei* 431, enhancing beneficial properties and consumer acceptance. This study provides promising information about the potential of these developed beverages (Herrera-Ponce et al., 2022).

Technological optimization is also advancing in the fortification of new cereal beverages with omega-3 polyunsaturated fatty acids (PUFAs). This includes improving processes to enhance the nutritional properties of beverages made from cereals with a high content of essential amino acids, surpassing the recommendations of the World Health Organization (Khastayeva et al., 2023). Similarly, central composite design has been effective in analyzing formulations of functional carob-based kefir (KLB), containing carob, whey permeates, and oat flour. The growth in substrates, radical-scavenging activity, and acceptability of the fermented KLB increased dose-dependently (M'hir et al., 2021).

Advancements in understanding the influence of microorganisms on the sensory characteristics of fermented beverages are also notable. However, a more detailed sensory analysis that accurately describes changes in flavor, acidity, and sweetness would be beneficial. Moreover, exploring methods to adjust these variations to align with consumer preferences and discussing practical implications for the food industry could enrich these findings (Masiá et al., 2021).

Despite these improvements, challenges related to the appearance, texture, and nutritional profile of these products persist, as they are often associated with yogurt-like products (Kasim et al., 2022). Research into the nutritional composition of these products has made progress, such as studies investigating oat oil emulsions. These emulsions are stabilized and incorporated into complex distribution systems, providing omega-3 and omega-6 fatty acids in drinkable yogurts, while maintaining excellent thermal stability throughout the process (Valoppi et al., 2019).

Addressing the challenges related to antinutrients like phytate, which impact the solubility and functionality of food ingredients, is crucial for developing more nutritious foods. It is important to consider a broader range of issues, including the unbalanced composition of amino acids and low absorption of B vitamins. A holistic approach, incorporating processing and formulation strategies, is essential for improving the nutritional quality of foods. Future research should focus on integrated solutions that comprehensively address these challenges to meet dietary needs (Yan et al., 2023).

In the development of cereal-based beverages, the potential presence of toxins has been a significant concern. Recent research established and validated a methodology for identifying various mycotoxins in oat, almond, soy, and rice-based beverages. The analytical method revealed these mycotoxins in approximately 95% of the samples. However, the risk to consumers is minimal, except for a specific compound, FA, recognized as a concern by international authorities (Juan et al., 2022).

Food safety challenges are prevalent in various regions, particularly in countries not yet classified as emerging. In Africa, the traditional beverage “kounou” is rich in

macronutrients and has notable antioxidant potential. However, its hygienic-sanitary quality presents deficiencies, hindering commercialization. For cereal-based beverages to be considered nutritious and beneficial, they must meet recommended quality control standards to ensure safety and enhance health benefits for consumers (Bayoï et al., 2021).

Considering aspects from an economic options standpoint, oats are an easy-to-grow cereal with high productivity and low cost compared to other traditional grains used in fermented beverages, such as barley and wheat. Its use expands the raw material base, reduces production costs, and increases economic forecasts, especially when processed in malted or germinated form, which enhances the nutritional and functional value of the final product (Miller et al., 2024; Y. Yu et al., 2023).

Oat-based fermented beverages meet the growing demand for functional, lactose-free, and gluten-free foods, expanding the consumer audience, including people with dietary restrictions (Angelov et al., 2018; Aparicio-García, Martínez-Villaluenga, Frias, & Peñas, 2021). The development of these products adds value to oats, which are traditionally undervalued, and allows the creation of beverages with antioxidant, prebiotic, and probiotic properties, which can be marketed at prices higher than convenience beverages (Angelov et al., 2018).

5 CONCLUSIONS

Oats stand out as an exceptionally promising substrate for the development of functional and probiotic beverages due to their high β-glucan content, fermentability, and capacity to support the growth of beneficial microorganisms. The evidence synthesized in this review demonstrates that oats provide technological advantages related to viscosity, stability, and antioxidant potential, which can be strategically exploited in industrial formulations. These insights have direct practical implications for manufacturers seeking to design beverages with improved texture, nutritional density, and consumer appeal.

Despite these strengths, challenges remain regarding the management of antinutritional factors, control of phase separation, and the need for more consistent sensory optimization. Future research should integrate processing strategies, ingredient selection, and real-time monitoring tools to enhance the nutritional quality and safety of cereal-based beverages. By addressing these aspects, the food industry can better harness the full potential of oats to develop high-quality, health-promoting plant-based beverages that meet growing market demands.

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Authorship contributions

1 – Dannyele Fernanda Souza Oliveira

Master's degree in Food Science and Technology from the University of Passo Fundo
https://orcid.org/0000-0001-8441-9922 • 200193@upf.br
Contribution: Conceptualization, Writing – original draft, Writing – review & editing

2 – Luciane Maria Colla

PhD in Food Engineering and Science from the Federal University of Rio Grande
https://orcid.org/0000-0001-9745-4452 • lmcolla@upf.br
Contribution: Conceptualization, Project administration, Supervision, Validation, Writing – review & editing

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