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Review

Fermented and Non-Fermented Rice-Based Beverages: Processing, Composition and Health Effects—An Overview

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Abstract

Driven by the demand for plant-based functional foods, rice-based beverages represent versatile matrices rich in essential nutrients and phytochemicals. This narrative review, based on a structured search on PubMed and Scopus with a PRISMA-based flow diagram, synthesizes 45 primary studies to compare the processing techniques, chemical composition, and potential health effects of non-alcoholic fermented and non-fermented rice beverages. Non-fermented routes rely on physical extraction and enzymatic hydrolysis to preserve a sweet, allergen-free profile, whereas fermented processing utilizes filamentous fungi such as koji (rice inoculated with *Aspergillus oryzae*), lactic acid bacteria, kefir grains or autochthonous microorganisms naturally present in the raw materials to biochemically transform the substrate. Pigmented and germinated rice provided the highest phenolic, γ-oryzanol and γ-aminobutyric acid contents, whereas commercial rice drinks were low in protein and polyphenols. Fermentation increased some compounds, such as free amino acids and B vitamins, but in cell models it reduced the antiproliferative and cytokine-modulating activity of a white rice beverage. Human evidence is scarce and derives from clinical trials with limited sample sizes on bowel function, gut microbiota composition, postprandial glycemia and blood pressure, whereas antioxidant, anti-inflammatory and antiproliferative effects derive from in vitro, cell and animal studies. In conclusion, the functional value of rice beverages depends on grain variety, processing and microorganism, and fermentation does not universally improve it. Larger, well-controlled clinical trials are needed to confirm their potential health effects.

Keywords: rice-based beverages; fermentation; bioactivity; antioxidant capacity; gut microbiota; functional foods

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1. Introduction

In the current global nutrition context, there is a growing demand for plant-based foods and beverages that not only meet basic dietary needs but also offer specific functional health benefits. This trend may be associated with consumers' perception of new products, which is influenced by factors such as health benefits, familiar flavor, nutritional composition, sensory characteristics, and environmental aspects [1]. In this sense, cereal-based beverages have emerged as promising vehicles for bioactive compounds [2]. Rice (*Oryza sativa*), due to its technological versatility, has established itself as a preferred matrix for the

development of these beverages [3]. Although rice is primarily a source of carbohydrates, it also contains minor phytochemicals, essential nutrients, and bioactive compounds that have been associated with protection against diseases and a positive impact on the immune system [3]. As a result, to enhance sensory characteristics, promote bioenrichment, improve health attributes and extend shelf life, fermentation processes with lactic acid bacteria (LAB) or filamentous fungi are often used [4,5]. However, the nutritional impact of rice-based beverages (RBBs) varies depending on their processing: while non-fermented beverages offer a digestible, allergen-free source of energy, fermented beverages may contain live microorganisms, higher levels of some bioactive compounds, and greater nutrient bioaccessibility [1]. These effects depend on the beverage, the microorganisms, the processing conditions and the survival of the microorganisms during storage. Fermented beverages should be distinguished from beverages that are only supplemented with live cultures or other functional ingredients [5]. In addition, alcoholic rice beverages, such as rice wines and beers, form a different category, as ethanol is a confounding factor for any health effect [6]. Despite their popularity, scientific literature often treats these categories separately. Therefore, it is necessary to collect and synthesize data to understand how processing techniques modulate chemical composition and influence specific health effects. Beyond nutrition, these beverages have been studied for their potential to modulate gut microbiota, as well as for antioxidant, anti-inflammatory, and immunomodulatory activities. Furthermore, their potential role in metabolic health and their antiproliferative activity in vitro represent areas of growing interest, although most of this evidence is preclinical.

Several reviews have previously addressed specific aspects of this topic, including fermented plant-based dairy alternatives [1], the environmental impact and nutrient composition of plant-based drinks [2], functional beverages from cereal grains [7], the potential health benefits of amazake [8], and traditional rice-based fermented products, including alcoholic beverages [9,10]. However, to date, no review has jointly compared non-alcoholic fermented and non-fermented RBBs, nor integrated how rice variety and processing shape their composition, bioaccessibility and potential health effects across in vitro, animal and human studies. The aforementioned reviews have addressed related but isolated aspects of these beverages, often combining alcoholic and non-alcoholic products or focusing on a single product type.

Therefore, this overview aims to compare the nutritional and bioactive composition and the potential health effects of non-alcoholic fermented and non-fermented rice-based beverages, considering how rice variety and processing, including fermentation, shape them.

1.1. Global Importance and Sustainability of Rice

Worldwide tendency toward plant-based diets, driven by a growing population concerned about health, animal welfare and the need for more sustainable agricultural systems, has redirected the beverage market [2]. In this context, non-dairy beverages, which are marketed as alternatives to milk, have experienced a rapid increase, especially among intolerant populations unable to digest lactose, individuals with allergies and those following vegan or flexitarian diets [3].

Rice is considered one of the crops of critical importance worldwide. Global rice production for the 2025/26 season was estimated at 551.5 million tonnes of milled rice, representing a 0.9% increase compared to 2024/2025 [11]. Rice originated in Asia, probably in India, more than 10,000 years ago; however, China was the first country to cultivate it. Production later escalated to Europe around 800 B.C. and reached Spain during the Muslim invasion. Within the European Union, Italy is the largest rice producer, with 1.5 million tonnes in 2020, followed by Spain, which produced a total of 493,066 tonnes of rice the same

year. In Spain, rice cultivation in 2024 was distributed as follows: Andalucía (29.4% of total), Extremadura (24%), Cataluña (22.5%) and Valencian Community (18%) [12].

The importance of the crop is linked to its potential in food innovation, as its composition allows the development of value-added products that may contribute to several Sustainable Development Goals (SDGs), particularly SDG3, "Good Health and Well-being" [13]. Beyond its nutritional relevance, rice plays a central role in global sustainability strategies. International initiatives such as the CGIAR Research Program focus on improving the social, economic and environmental sustainability standards of rice systems, reporting contributions to SDG12, "Responsible Consumption and Production" through the establishment of sustainability standards, decision-support tools, and quantitative impact indicators that promote resource efficiency and responsible production systems [14,15]. However, these contributions refer to rice production systems, and the specific contribution of RBBs to these goals has not been evaluated.

1.2. Rice Grain Composition and Rice-Derived Products

Rice contains moderate amounts of protein and fat and is a source of B-complex vitamins such as niacin, riboflavin and thiamine [16]. In addition, different parts of the rice grain (bran, germ and endosperm) contain bioactive compounds that are highly beneficial to human health, providing protection against disease and positively influencing the immune system [17,18]. Rice composition can differ depending on the variety (white, brown, or pigmented), grain color (white, red, or black depending on the pigment content), and genetic modifications, such as "golden rice". White rice is mainly composed of starch, typically accounting for approximately 75–80% (w/w); however, it generally possesses lower concentrations of proteins and micronutrients due to the removal of the bran and germ layers during the milling process. In contrast, brown and pigmented varieties are considered nutritionally superior as they retain these outer layers, resulting in higher amounts of proteins, fiber, vitamins and minerals, as well as antioxidant compounds [19,20]. These varieties may also produce a lower glycemic response, although this depends on the cultivar and on cooking conditions [21]. The specific nutritional profiles of these diverse rice varieties are summarized in Table 1. These values correspond to the raw grain and should not be interpreted as the composition of the corresponding beverages.

Each variety of rice has a unique profile of bioactive chemicals that determine its functional potential. Lipid-soluble antioxidants, such as γ-oryzanol, tocopherols, and tocotrienols, are abundant in brown rice and are mostly found in the bran layer [3]. Proanthocyanidins, characteristic of red rice varieties, are responsible for their distinctive color and strong antioxidant properties [3,19]. Black rice is often recognized for its nutritional density, contains the highest concentration of anthocyanins, especially cyanidin-3-glucoside; and can also reach approximately 4.2–10.8% fiber, which exceeds the levels found in white varieties [3,19]. Furthermore, the genetically modified "golden rice" is unique, as it has been biofortified to biosynthesize β-carotene (provitamin A) inside the endosperm in order to address micronutrient deficiencies while retaining a proximate and nutritional composition similar to conventional varieties [27].

As highlighted previously, rice and its varieties possess a unique composition that enables the production of a wide range of products, including flours, starches used as thickeners, and rice bran oil. Within this group of rice-based products, liquid products, such as RBBs, are experiencing a rapid increase in demand. The growing interest in plant-based beverages, such as RBBs, comes from the need to obtain a beverage with properties similar to those of dairy milk [1]. These beverages can be classified into two main groups, based on the production process and from a technological perspective: fermented and non-fermented beverages. Fermented RBBs are characterized by using microorganisms

such as LAB, yeasts or filamentous fungi to transform sugars mainly into organic acids and, in alcoholic beverages, into ethanol, whereas non-fermented RBBs are extracts obtained through grain dispersion and, usually, through enzymatic hydrolysis. This process uses amylases to break starch chains into simple sugars, resulting in a stable and sweet beverage without the intervention of fermentation processes [1,7]. Alcoholic rice beverages, such as rice wines and beers, and distilled products constitute a different category and are outside the scope of this review (see Section 2).

Table 1. Nutritional profile and main bioactive compounds of different rice varieties.

Component (per 100 g Raw Grain)		Proteins (g)	Fiber (g)	Lipids (g)	Carbohydrates/Starch (g)	Main Bioactive Compounds	References
Rice Varieties	**White**	6.8–7.6	1.2–2.8	<1.0	75.0–80.0	Fe 0.5 mg, Zn 0.2 mg, Mg 13.0 mg, Mn 0.9 mg, and vitamin E 0.3 mg	[3,19,22,23]
	Brown	7.5–8.5	2.2–3.6	2.0–3.0	76.2–81.3	γ-oryzanol 18–63 mg, Fe 1.7 mg, Zn 1.8 mg, Mg 143 mg, vitamin E 0.6 mg, tocopherols 0.6 mg, GABA 32.0 mg, and total polyphenols 94.52 mg GAE	[3,22–25]
	Red (PG)	7.0–10.0	4.2	2.0–2.5	75.0–80.0	Proanthocyanidins 53.45 mg, catechin 6.65 mg, and total polyphenols 237.78 mg GAE per g of polar extract	[3,22]
	Black (PG)	7.6–10.5	4.2–10.8	1.4–3.4	75.0–77.2	Anthocyanins (Cyanidin-3-glucoside accounting for ~89%), phenolic acids (protocatechuic), and total polyphenols (226.70 mg per g of extract)	[19,22,26]
	Golden (GM) [a]	8.1	17.0	1.4	84.6	β-carotene (Provitamin A: 0.36 mg), α-carotene (0.035–0.132 mg), β-cryptoxanthin (0.023–0.046 mg)	[22,27]

[a] Paddy grain, dry-weight basis. GABA: γ-aminobutyric acid; GAE: gallic acid equivalents; GM: genetically modified; PG: pigmented rice variety.

2. Materials and Methods

2.1. Literature Search

For this narrative review, the principles of systematic searching were followed, and the scientific articles were obtained from PubMed and Scopus databases. The study selection process was described using a flow diagram adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [28]. However, the review was not registered, no meta-analysis was performed, and no formal risk-of-bias assessment was carried out (see Section 2.3); therefore, it does not meet all the requirements of a systematic review. A preliminary search of recent reviews and of the PubMed MeSH

database was performed to identify relevant keywords and synonyms. The same search string, ("rice beverage*" OR "rice-based beverage*" OR "rice-fermented beverage*" OR "rice-based fermented" OR "rice-based alcoholic" OR "rice drink*" OR "rice milk*" OR ricemilk* OR "rice water" OR "rice wine*" OR "rice beer*" OR amazake OR makgeolli) AND (bioactive* OR antioxidant* OR phenolic* OR polyphenol* OR probiotic* OR prebiotic* OR synbiotic* OR microbiota OR microbiome OR "health benefit*" OR "health effect*" OR "health-promoting" OR "nutritional value" OR "nutritional composition" OR "nutritional quality" OR therapeutic), was used in both databases, searching by title, abstract and keywords. Although alcoholic beverages were outside the scope of this review, terms for alcoholic rice beverages ("rice-based alcoholic", "rice wine*", "rice beer*" and makgeolli) were retained in the search string so as not to miss studies on these beverages with an alcohol content of 1.2% (*v*/*v*) or lower, which were eligible (see Section 2.2). The search was limited to original articles and reviews with at least an abstract available in English and published between 2016 and 2026, in order to focus on the most recent decade of research. The search was carried out on 15 October 2026 and yielded 564 records from Scopus and 342 from PubMed. After removing 287 duplicates, 619 unique records were screened by title and abstract and, when necessary, by full-text examination.

2.2. Eligibility Criteria

Inclusion criteria comprised original research articles on non-alcoholic RBBs, as consumed, that reported data on nutritional or bioactive composition, bioaccessibility or biological effects, including in vitro, animal and human studies. RBBs were defined as beverages in which rice was the main substrate, such as non-fermented rice drinks, rice water, amazake and other koji-fermented beverages, kefir-type and lactic acid-fermented rice beverages, and commercial rice drinks. Studies focused on processing were included when they reported compositional data of the beverage, so that the eligibility criteria were not restricted to health outcomes.

The following exclusion criteria were applied: (i) products other than RBBs, such as rice grain, bran, flour or extracts, semisolid fermented rice, cereal blends in which rice was not the main substrate, and starters; (ii) alcoholic beverages, defined as beverages with an alcohol content above 1.2% (*v*/*v*), the threshold above which the alcoholic content must be declared in the European Union (Regulation (EU) No 1169/2011); (iii) beverages with added ingredients to which the observed effect could not be separated from the rice beverage, such as non-rice ingredients, rice-derived additives (e.g., rice bran or bran peptides), or fortificants; (iv) studies on isolated microorganisms, purified compounds, solvent fractions or by-products (e.g., lees) studied on their own; (v) studies focused on the selection of starter strains rather than on the beverage; (vi) studies without nutritional, bioactive or health-related data; (vii) studies reporting only label- or database-derived nutritional data; and (viii) reviews and non-original articles. Reviews retrieved by the search were not counted as included studies and were not tabulated. However, they were used in this review when their content was relevant. Sweeteners, flavorings, salt and stabilizers added only for palatability or texture, and in the same amount to all samples compared, were not considered an exclusion criterion. Alcoholic beverages were excluded because they are classified as carcinogenic to humans and no safe level of alcohol consumption has been established [6,29], so their presence would confound the interpretation of any health effect attributed to the beverage. Studies on rice grain, extracts or isolated compounds, and studies excluded under criteria (ii), (iii) and (iv), were used for contextual purposes only when relevant to the text and were neither counted as included studies nor tabulated. Similarly, information from additional sources such as government websites, specifically the U.S. Department of Agriculture (USDA) FoodData Central database [22] (FDC IDs: 168883, 169703, 2710838

and 2710825) and the Spanish Food Composition Database (RedBEDCA) [23], professional associations, books, press articles and official documents was used only to provide context and was not counted in the study selection process.

2.3. Study Selection, Data Extraction and Synthesis

Screening by title and abstract and, when necessary, full-text assessment were performed by a single researcher, applying the predefined eligibility criteria. After screening, 51 reports were assessed in full text, and six were excluded: two because the beverages contained added non-rice ingredients, one because the beverage contained added rice bran, one because the beverage was prepared from a rice extract, one because only lipid fractions of the beverages were tested and one because the full text was not available. Finally, 45 primary studies were included in this review. Of these, 28 reported compositional or processing data (five of them including simulated gastrointestinal digestion), six were cell-based studies, three were animal studies, and eight were human studies. Two of the included studies were published in Japanese with an English abstract, and their data were obtained from the English abstract and tables [30,31]. The remaining included studies were published in English. The study selection process is illustrated in Figure 1.

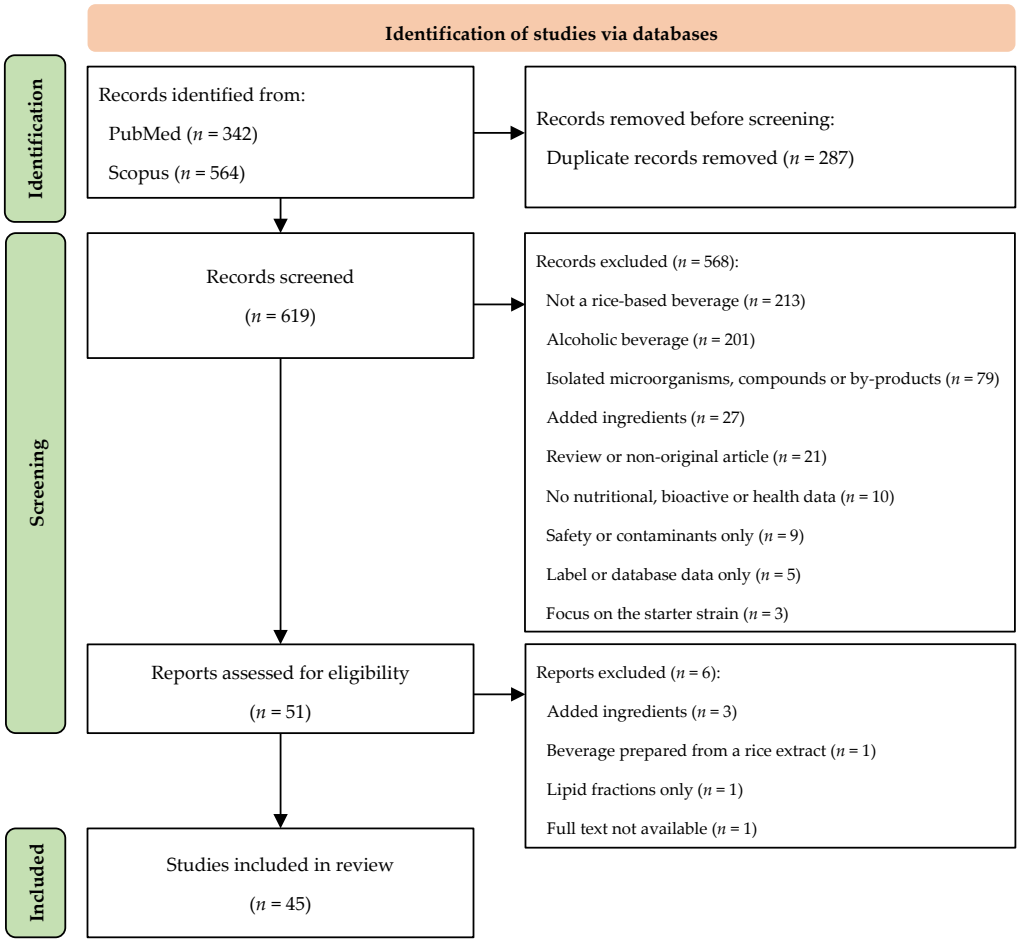

Figure 1. Flow diagram of the study selection process, adapted from the PRISMA 2020 statement [28].

Data extracted from each primary study included author and year, country, beverage, rice variety, fermentation and microorganism, model and design, comparator, main outcomes and limitations (Table S1). Given the heterogeneity of beverages, designs and outcomes, the findings were synthesized narratively. Composition data are presented by rice variety and processing (Section 3, Table 4), and health-related evidence is presented

by rice variety and, within each variety, by level of evidence, from in vitro and cell-based studies to animal and human studies (Section 4, Table 5).

No formal assessment of the quality or risk of bias of the included studies was performed. Consequently, the findings of this review should be interpreted as a qualitative synthesis of the available evidence and not as an estimate of the magnitude of the effects. The design, sample size, comparator and main limitations of each study are reported in Table S1 and are considered throughout the text.

3. Rice-Based Beverages: Processing and Composition

3.1. Processing Technologies for Non-Fermented and Fermented RBBs

Regardless of the manufacturing technique, the production of most RBBs follows several common first steps, although their order and conditions differ between rice beverages, rice water and amazake [13]. The sequence starts with the cleaning and selection of raw rice grains to ensure quality [13,32]. This is followed by soaking, where rice is immersed in water to hydrate the kernels and facilitate uniform softening, for example, for 6–24 h at rice-to-water ratios of 1:4 to 1:9 (w/v) in rice beverages [33,34] or overnight before steaming in amazake [35,36]. Next, thermal treatment is applied through steaming or boiling to obtain starch gelatinization, which makes its carbohydrates accessible for either mechanical extraction or enzymatic and microbial transformation [35,37]. In rice beverages, rice then goes through mechanical processing, such as grinding, blending or wet-milling, to boost the release of solids and nutrients into the water [33,38,39]. Finally, separation through filtration is carried out using tools like cheesecloth, muslin cloth or sieves to isolate the liquid extract from the solid rice residues, resulting in the refined base for the beverage [4,13,33,37]. In contrast, rice water is obtained by soaking cooked rice in water without grinding [37,40]. These initial steps establish the foundation for the two main processing routes whose specific procedural differences are illustrated in Figure 2.

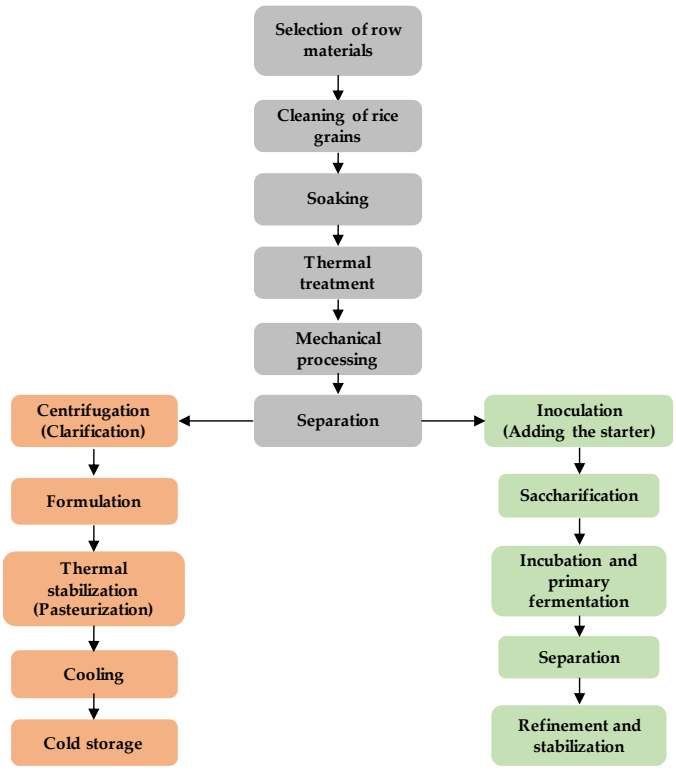

Figure 2. Rice-based beverage processing flowchart: common (grey), non-fermented (orange), and fermented (green) steps.

Non-fermented beverages focus on physical extraction and preservation [13,41]. After the common initial steps, the extract is filtered using fine meshes or cheesecloth to obtain a plant-based beverage, and in some instances it is refined by homogenization to ensure a smoother consistency (Figure 2, orange) [33,34]. This is followed by formulation, where basic ingredients such as sugar, salt, gums or vegetable oil are incorporated to enhance palatability and stability [39,42], and, in commercial products, calcium, iodine or vitamins may be added [42–44]. This route lacks the natural preservation provided by high acidity, which is why the beverage must go through thermal stabilization to kill microbes and avoid spontaneous fermentation; for example, a rice beverage produced by a local Spanish company was heat-treated at 85 °C for 5 min, and laboratory rice beverages at 65 °C for 30 min or at 80 °C for 5 min [32–34]. However, such heat treatments can exceed the gelatinization temperature of rice starch, which depends on the rice variety and milling fraction [45], causing the starch granules to swell and transition from an ordered crystal structure to a disordered gel state, potentially leading to undesirable viscosity. Accordingly, sterilization at 120 °C for 20 min produced a solid texture in white, black and red rice beverages, which made this treatment unsuitable [33]. Heating also modifies bioactive compounds. In germinated red jasmine rice beverage, γ-aminobutyric acid (GABA) decreased as the temperature increased from 80 to 121 °C, whereas 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity increased at 80–100 °C and decreased at 121 °C [46]. To prevent excessive viscosity and maintain a fluid consistency, pretreatment with amylolytic enzymes, such as α-amylase and glucoamylase, is often required during a "liquefaction" and "saccharification" stage to hydrolyze the starch into smaller, soluble saccharides before the final stabilization [38,47,48]. Non-thermal techniques have also been applied; for example, ultrasound-assisted production increased the anthocyanin yield of a purple rice beverage four-fold compared with the traditional method [49]. The final product is packaged and stored under refrigeration to maintain stability and safety [32].

On the contrary, fermented beverages are produced through a biochemical transformation route (Figure 2, green), initiated by inoculation after thermal processing and cooling, in which a starter culture such as koji (steamed rice inoculated with the filamentous fungus *Aspergillus oryzae* or, in black koji, *Aspergillus luchuensis*), kefir grains or a defined LAB culture is used [8,32,50,51]. Alternatively, cooked rice can be left in water to ferment spontaneously through the action of the autochthonous microorganisms present in rice and water [37,40]. The diversity of these microorganisms and their specific technological roles are summarized in Table 2. In amazake, rice koji is mixed with cooked rice and water and incubated at 50–60 °C for 6–24 h, so that koji amylases saccharify the starch into glucose and oligosaccharides without alcoholic fermentation [36,52–54]. In lactic acid-fermented beverages, LAB convert sugars mainly into organic acids; in some studies, glucose was added before fermentation, which increased the energy and carbohydrate content of the final beverage [32]. The duration of this step can vary from about 10–18 h for spontaneously fermented rice water [37,40,55] to 24–72 h for kefir-type and LAB-fermented rice beverages [50,56]. Acidity and alcohol content are different parameters and are reported separately. An 18 h fermentation was used to reach a pH below 5.5 in red rice water [55]. Rice drink kefirs had a lower pH than cow's milk kefir and contained 0.007–0.015% (*v*/*v*) alcohol [50], whereas no alcohol was detected in fermented rice water produced at 37 °C for 16 h [37]. Once fermentation is completed, the liquid is recovered through filtration to separate it from the solid residues, and the final product may then go through pasteurization to avoid microbial activity [36,37,51]. Alcoholic rice beverages, such as rice wines (e.g., sake, huangjiu and makgeolli) and rice beers, involve longer alcoholic fermentations, from about 4 days to 6 weeks [10,57–63].

Table 2. Key microorganisms of fermented rice-based beverages.

Category	Microorganisms (Strains When Reported)	Primary Role	Beverage	References
Filamentous fungi (koji)	*Aspergillus oryzae* (yellow koji); *Aspergillus luchuensis* MEM-C (black koji)	Produce amylolytic and proteolytic enzymes that saccharify starch into glucose and oligosaccharides (e.g., isomaltose)	Amazake	[36,51–54]
LAB (defined cultures)	*Lactiplantibacillus plantarum* JSA22; *Pediococcus acidilactici* FSPO-PJ1; *Streptococcus thermophilus*; *Lactobacillus delbrueckii* subsp. *bulgaricus*; *Lactobacillus acidophilus* H9; commercial consortia of *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus* (Danisco® VEGE033), also containing *L. acidophilus* NCFM® and *Bifidobacterium animalis* subsp. *lactis* HN019® (VEGE053), plus *Lactiplantibacillus plantarum* (VEGE022) or *Lacticaseibacillus paracasei* (VEGE061)	Produce lactic acid and lower pH; strain-dependent changes in amino acids, B vitamins and phenolic compounds	Fermented rice drinks and rice beverages; riceberry amazake fermented with LAB	[32,64–66]
Other bacteria (defined cultures)	*Bifidobacterium bifidum*; *Bifidobacterium longum* B379M; *Propionibacterium freudenreichii* subsp. *shermanii* KM-186; *Bacillus coagulans* MTCC 5856	Acidification; strain- and variety-dependent changes in antioxidant activity and polyphenols	Fermented rice beverages	[65]
Autochthonous microorganisms (spontaneous fermentation)	*Leuconostoc lactis*, *Weissella confusa*, *W. cibaria*, *Lactococcus lactis*, *Limosilactobacillus fermentum* and other LAB; *Weissella* and yeasts; Proteobacteria (*Pantoea*) and Firmicutes (*Saccharibacillus*, *Bacillus*)	Acidification and production of metabolites; phytase activity	Fermented rice water	[40,55,67]
Kefir grains	Consortium of LAB, acetic acid bacteria and yeasts	Acidification, volatile compounds and low ethanol production ($\leq$0.015% *v*/*v*)	Rice drink kefir	[50,56]

LAB: lactic acid bacteria.

To summarize the main technical and functional distinctions discussed in this section, Table 3 provides a side-by-side comparison of the two processing pathways.

Table 3. Key differences between non-fermented and fermented rice-based beverage processing pathways.

Feature	Non-Fermented Route	Fermented Route	References
Primary mechanism	Physical extraction (soaking, grinding and filtration), often combined with enzymatic hydrolysis of starch (α-amylase, glucoamylase)	Biochemical transformation: filamentous fungi in koji saccharify starch (amazake); LAB, kefir grains or autochthonous microorganisms produce organic acids	[33,37,38,47,48,52]
Microbial role	Prevented by heat treatment (e.g., 85 °C for 5 min or 65 °C for 30 min); sterilization at 120 °C for 20 min caused gelation	Starter cultures or autochthonous microorganisms are required; alcohol ≤ 0.015% (*v*/*v*) in rice drink kefirs and not detected in fermented rice water	[32,33,37,50]
Composition	Depends on rice variety, milling fraction and germination; commercial drinks are low in protein (≤0.5 g/100 mL), polyphenols and iodine unless fortified	May increase free amino acids, B vitamins, lactic acid, phenolics and mineral release in vitro, but changes are strain-, variety- and matrix-dependent	[42,43,55,65,66,68–70]
Final profile	Near-neutral pH (5.9–6.9); sweet taste from starch hydrolysis or added sugar; acceptability linked to aromatic varieties	Lower pH; sweet taste only when high glucose addition; new volatile compounds	[33,39,42,50,52,56]

LAB: lactic acid bacteria.

3.2. Nutritional and Bioactive Composition of Non-Fermented vs. Fermented Rice-Based Beverages

The nutritional and bioactive composition of RBBs can change depending on the rice variety, the processing and whether the substrate goes through fermentation, as shown in Table 4. However, these data were obtained with different formulations, dilutions and analytical methods, so values should not be compared directly across studies. For example, the energy content of 3.17 kcal per 100 g, with 0.19 g of fat, reported for an unfermented white rice beverage corresponds to a beverage with 98.68% moisture in which carbohydrates were not detected, whereas the fermented samples of the same study were prepared after the addition of glucose, which increased their energy content (34.6–46.0 kcal per 100 g) [32]. White rice, which is the most common substrate, is nutritionally limited due to the milling process, since it eliminates the bran and germ layers [19]. Laboratory white rice beverages contained 1.5 g of protein per 100 g [33]. Commercial rice drinks provided 37–55 kcal, 8.0–11.0 g of carbohydrates and no more than 0.5 g of protein per 100 mL, according to their labels [42]. Commercial rice drinks also had the lowest polyphenol content among plant-based beverage alternatives [69], the highest free sugar content among regular plant-based drinks [44], and lower levels of most elements than soy, oat or almond drinks, although the bioaccessibility of these elements in vitro was the highest (9.0–90.8%) [71]. The high content of rapidly available carbohydrates in some RBBs should also be considered. A commercial koji amazake contained 26.1 g of glucose per 118 g bottle [52]. Lange and Nakamura [8] noted that the long-term consumption of amazake could contribute to the development of diabetes and obesity, although the trials they reviewed did not report adverse events or changes in blood glucose or body weight. In addition, unfortified rice drinks contained very little iodine (median 4.1 µg/kg) compared with cow's milk [43]. One glass of rice drink provided only 0.1% of the requirement of the limiting essential amino acid, compared with at least 24% for semi-skimmed milk [44]. Therefore, unfortified rice drinks differ nutritionally from cow's milk, mainly in their protein and iodine contents [72].

Regarding the fatty acid profile of commercial rice drinks, it largely reflects the added vegetable oil [73,74].

Pigmented rice varieties, such as red and black rice, offer a greater functional value because of their concentration of specialized flavonoids and phenolic acids [3,19]. In beverages, the phenolic content was highest in black rice drink (24.4 mg gallic acid equivalents (GAE)/100 g), followed by red (15.6 mg GAE/100 g) and white rice drinks (7.1–10.6 mg GAE/100 g) [65]. Similarly, pigmented rice beverages showed higher total phenolic content (56.6–64.5 µg/mL) and oxygen radical absorbance capacity (ORAC) values than non-aromatic white rice beverage [39]. Black rice also provided the highest phenolic content and antioxidant activity in plant-based beverages prepared from white, black and red rice [33]. The same was observed in fermented rice water prepared from black, red and brown rice (8.02, 4.75 and 1.97 mg of total polyphenols per 100 mL, respectively) [37]. Similarly, Riceberry amazake contained more protein, fat, vitamin B1, minerals and phenolics than amazake made from Japanese white rice [36]. In addition, a Sinlek iron rice drink provided 1.47–2.74 mg of iron per 100 mL, compared with 0.5 mg per 100 mL in a white rice drink [47]. Brown and germinated rice also modify the composition of the beverage. Amazake made from germinated rice contained 27.65 mg/100 g of γ-oryzanol and 271.53 mg/100 g of GABA, compared with non-detectable γ-oryzanol and 163.95 mg/100 g of GABA in amazake made from milled rice [68]. Likewise, a brown rice amazake provided 32 mg of γ-oryzanol and 3.2 g of fiber per 350 g pack, compared with 1.8 mg and 1.1 g in a white rice amazake [35]. Germinated brown rice beverages contained more lipids, free sterols, phytosterol esters and oryzanols than beverages from non-germinated brown or white rice [38]. Germinated red rice beverage also contained more raffinose than red rice beverage [77]. However, germination may also reduce other compounds, as anaerobic germination of Riceberry rice increased GABA by up to 58.6% but decreased total phenolics and anthocyanins by 26.5% and 44.4%, respectively [48]. The milling fraction is also relevant, since rice beverages prepared from whole green rice and its bran contained more phenolics and flavonoids and showed higher antioxidant activity than white rice beverage [34].

The processing route creates a difference in the beverage's final properties and nutrient profile [13]. Non-fermented beverages, like rice drinks or rice water, focus on physical extraction to release native nutrients into a liquid base without microbial alteration [33,78]. While these drinks retain the native characteristics of the grain, they may also contain phytic acid, an antinutrient that binds essential minerals like iron, calcium, and zinc, which limits their absorption [3,24]. The extraction of minerals into rice water also depends on the rice type and the processing. The lowest extraction was observed for brown rice [78], whereas fermented rice water retained more minerals after hot water boiling without parboiling [79]. In fermented beverages, the metabolic activity of LAB, yeasts and filamentous fungi can modify the composition of the substrate. Spontaneous fermentation of red rice water for 18 h increased protein by 163.52% and free amino acids by 35.47%, increased phytase activity, and increased the release of calcium, iron and zinc during simulated digestion by approximately 1190%, 566% and 93%, respectively [55]. Fermentation of Riceberry amazake with *Pediococcus acidilactici* FSPO-PJ1 increased lactic acid, eight amino acids (histidine, lysine, cysteine, glycine, proline, alanine, leucine and methionine), vitamins B1, B2, B3 and B9, and total phenolics (1.274 vs. 1.080 mg GAE/g) compared with conventional Riceberry amazake [66]. Similarly, koji amazake from jasmine rice showed a higher total phenolic content and DPPH scavenging activity than non-fermented jasmine rice [54]. The type of koji and the saccharification process also matter. Black koji amazake contained more isomaltooligosaccharides, citric acid and ferulic acid than yellow koji amazake [51]. Double saccharification produced amazake with about 20 times more isomaltose than commercial amazake [53].

Table 4. Nutritional and bioactive composition of non-fermented (NF) and fermented (F) rice-based beverages.

Rice Variety	Beverage and Processing	Energy (kcal)	Protein (g)	Fat (g)	Fiber (g)	Carbohydrates (g)	Key Bioactive Compounds (mg)	Vitamins (mg)	Reference
White rice									
White	Rice beverage, pasteurized (65 °C, 30 min) (NF)	24.21	1.52	0.15	–	4.43	–	–	[33]
	Rice beverage (water 91.9%, rice 8%, sea salt 0.1%), heat-treated at 85 °C for 5 min (NF)	3.17	0.26	0.19	0.01	n.d.	TSP 0.72–1.75	–	[32]
	Fermented with LAB consortia after adding glucose (F)	34.6–46.0	0.22–0.30	0.21–0.39	n.d.–0.05	7.8–10.8	–	–	
	Koji amazake, commercial (F)	108.0	1.2	0.3	0.2	25.2	–	–	[52]
	Malted rice amazake, 35 g of paste diluted to 150 mL (F) †	51.1	0.8	0.1	0.4	12.0	–	–	[75]
	Koji amazake from Japanese rice (F)	172.84	3.28	0.48	–	38.85	TPC 198.33	B_1 0.02; B_2 0.02	[36]
	Koji amazake (F)	90.0	1.4	0.2	0.3	20.6	γ-Oryzanol 0.51	–	[35]
	Koji amazake from milled rice (F)	–	–	–	–	–	GABA 163.95; γ-oryzanol n.d.	–	[68]
	Saccharified rice beverage (NF)	–	–	–	–	–	γ-Oryzanol 0.36	–	[38]

Table 4. *Cont.*

Rice Variety	Beverage and Processing	Energy (kcal)	Protein (g)	Fat (g)	Fiber (g)	Carbohydrates (g)	Key Bioactive Compounds (mg)	Vitamins (mg)	Reference
White	Commercial rice drinks, 10 products (NF) †	37–55	<0.5	0.6–1.3	<0.5	8.0–11.0	TPC 0.59–2.81	B_{12} 0.38 µg and D 0.75 µg (added in two products)	[42]
	Commercial rice drink (NF) †	–	–	–	–	–	(Poly)phenols 0.4	–	[69]
	Aromatic and non-aromatic rice beverages with 5% sugar and 0.125% gum (NF) †	–	–	–	–	–	TPC 0.74–1.01	–	[39]
	Rice beverages from Krasnodar and basmati rice (NF)	–	0.35–0.54	–	–	–	TPC 7.1–10.6	–	[65]
	Jasmine rice hydrolysate drink with honey (NF) †	62.61	0.53	0.09	–	14.92	TPC 1.15	–	[47]
	Rice beverage kefir from KDML 105 rice with 2.5% sucrose syrup (F) †	–	–	–	–	–	TPC 25.29–29.00	–	[50]
Brown and germinated rice									
Brown	Koji amazake (F)	97.1	1.7	0.9	0.9	20.5	γ-Oryzanol 9.14	–	[35]
Germinated brown	Koji amazake from germinated rice (F)	–	–	–	–	–	GABA 271.53; γ-oryzanol 27.65	–	[68]

Table 4. *Cont.*

Rice Variety	Beverage and Processing	Energy (kcal)	Protein (g)	Fat (g)	Fiber (g)	Carbohydrates (g)	Key Bioactive Compounds (mg)	Vitamins (mg)	Reference
Brown; germinated brown	Saccharified rice beverages (NF)	–	–	–	–	–	γ-Oryzanol 1.15 (brown) and 5.84 (germinated)	–	[38]
Brown	Fermented rice water (Puzhuthikar), control without additives (F) †	29.80	0.03	–	–	2.83	TPC 1.97; TFC 0.30	B_3 0.31	[37]
Brown	Aromatic brown rice beverage with 5% sugar and 0.125% gum (NF) †	–	–	–	–	–	TPC 3.77	–	[39]
				Pigmented rice					
Red	Rice beverage, pasteurized (65 °C, 30 min) (NF)	56.04	1.14	0.72	–	10.92	–	–	[33]
Black	Rice beverage, pasteurized (65 °C, 30 min) (NF)	39.91	1.75	0.57	–	6.95	TPC 77.03	–	[33]
Red	Rice beverage (NF)	–	0.35–0.54	–	–	–	TPC 15.6	–	[65]
Black	Rice beverage (NF)	–	0.35–0.54	–	–	–	TPC 24.4	–	[65]
Red	Fermented rice water (Mappillai Samba), control without additives (F) †	30.38	0.04	–	–	5.77	TPC 4.75; TFC 0.53	B_3 0.03	[37]

Table 4. *Cont.*

Rice Variety	Beverage and Processing	Energy (kcal)	Protein (g)	Fat (g)	Fiber (g)	Carbohydrates (g)	Key Bioactive Compounds (mg)	Vitamins (mg)	Reference
Black	Fermented rice water (Karuppu Kavuni), control without additives (F) †	30.00	0.06	–	–	5.81	TPC 8.02; TFC 0.73	B_3 0.14	[37]
Purple; red	Rice beverages with 5% sugar and 0.125% gum (NF) †	–	–	–	–	–	TPC 5.66 (purple) and 6.45 (red)	–	[39]
Red (germinated)	Germinated red jasmine rice beverage, before heating (NF) †	–	–	–	–	–	GABA 4.58	–	[46]
Black glutinous (germinated)	Drink brewed from roasted germinated rice at 98 °C for 3 min (NF) †	–	–	–	–	–	GABA 0.11; TPC 2.91; TAC 0.05	–	[76]
Riceberry (purple)	Koji amazake (F)	180.31	3.87	1.47	–	37.90	TPC 291.46; TAC 871.68	B_1 0.12; B_2 0.04	[36]
Riceberry (purple)	Koji amazake (F)	–	–	–	–	–	GABA 2.73; TPC 108.0	B_1 0.163; B_2 0.140; B_3 0.129; B_5 0.355; B_6 0.028; B_9 0.014	[66]
Riceberry (purple)	Koji amazake fermented with *Pediococcus acidilactici* FSPO-PJ1 (F)	–	–	–	–	–	GABA 2.74; TPC 127.4	B_1 0.346; B_2 0.213; B_3 0.177; B_5 0.200; B_6 0.012; B_9 0.021	[66]

Table 4. *Cont.*

Rice Variety	Beverage and Processing	Energy (kcal)	Protein (g)	Fat (g)	Fiber (g)	Carbohydrates (g)	Key Bioactive Compounds (mg)	Vitamins (mg)	Reference
Red; Hawm Nil	Rice drink kefirs from Red Hawm and Hawm Nil rice with 2.5% sucrose syrup (F) †	–	–	–	–	–	TPC 25.07–31.93 (Red Hawm) and 25.64–37.54 (Hawm Nil)	–	[50]
Sinlek (iron rice)	Rice hydrolysate drinks with honey, low and high dose (NF) †	58.72–118.08	0.31–0.67	0.04–0.07	–	14.28–27.23	TPC 1.33–2.08	–	[47]

Values are expressed per 100 g of beverage or, when marked with †, per 100 mL. Values were taken as reported in the original studies, except for those from [35,52,75,76], which were calculated from data reported per serving or package, and those from [32,37,39,46,50,66], which were converted from other units (mg/L in [32,37,50]; mg/mL in [46]; µg/mL in [39]; mg/g and µg/100 g in [66]). In [36], TPC and TAC are expressed per 100 g of dried extract. –: not reported; F: fermented; GABA: γ-aminobutyric acid; LAB: lactic acid bacteria; n.d.: not detected; NF: non-fermented; TAC: total anthocyanin content (cyanidin-3-glucoside equivalents); TFC: total flavonoid content (quercetin equivalents); TPC: total phenolic content (gallic acid equivalents); TSP: total soluble polyphenols (gallic acid equivalents).

However, the effect of fermentation on the bioactive properties of RBBs was not consistent across studies. Total phenolic content increased during 48–72 h of kefir fermentation of white, red and purple rice beverages [50]. Similarly, LAB fermentation of Riceberry amazake increased total phenolic content and antioxidant activity compared with amazake fermented with koji alone [66]. In rice beverages fermented with single strains, antioxidant activity increased in white, basmati and black rice drinks depending on the strain, but decreased in red rice beverage with all strains [65], whereas the antioxidant capacity of black rice drink kefir remained stable across fermentation conditions [56]. These results suggest that the outcome depends on the combination of rice variety and microorganism used. In a white rice beverage fermented with LAB, fermentation produced modest improvements, and phenolic retention after simulated digestion was about 8% [70]. After simulated digestion, the Trolox equivalent antioxidant capacity (TEAC) of this beverage increased 101.9-fold, and that of the unfermented beverage 30.7-fold, suggesting that digestion contributed to most of this increase, although both results were obtained with in vitro assays [70]. Regarding phytic acid, LAB fermentation of brown rice flour reduced its content by 37.33%, less than germination or extrusion [24]. However, only total phytic acid was determined, and the inositol phosphate forms (IP6–IP1) remaining after each treatment were not studied. Therefore, their implications for mineral chelation and bioaccessibility could not be assessed. In addition, phytic acid was not quantified in the included beverage studies, and a reduction in phytic acid or an increase in mineral release in vitro is not a direct measurement of mineral bioavailability or of absorption in humans.

Sensory acceptance is also a key factor for these beverages. Rice drinks made from red and aromatic varieties obtained the highest overall liking scores (5.6–5.7 on a 9-point hedonic scale, 161 consumers), associated with the "popcorn" aroma of 2-acetyl-1-pyrroline, whereas the dark color of pigmented rice drinks decreased the acceptability of their appearance [39]. Among commercial rice drinks, the overall sensory quality, assessed by a trained panel with a quantitative descriptive profile of 17 attributes of color, odor, flavor and texture, was rated highest for those with the highest sugar content [42]. In fermented beverages, LAB fermentation produced a pleasant aroma profile in a white rice beverage with specific starter consortia, according to a preliminary aroma test with 11 untrained panelists [32]. *Bifidobacterium bifidum* and *Bifidobacterium longum* B379M were considered the most promising strains for a rice beverage when the liking of appearance, texture, flavor, taste and overall acceptability was also considered [65]. In contrast, amazake made from germinated rice obtained low overall liking scores (4.67–4.9 on a 9-point scale) among 136 Portuguese consumers, which suggests that cultural familiarity influences acceptance [68]. A low-dose Sinlek iron rice drink obtained an overall acceptance score of 8.1 on a 9-point hedonic scale among elderly consumers [47]. A germinated black glutinous rice drink was moderately liked on a 9-point hedonic scale by 100 untrained consumers [76].

3.3. Food Safety Considerations

Rice accumulates more arsenic than other cereal crops, and inorganic arsenic, a class 1 carcinogen, is concentrated in the outer layers of the grain, reaching concentrations in rice bran and rice bran products 10–20 times higher than in bulk grain [80]. In rice-based products consumed by toddlers, including rice drinks, risk assessment showed little or no margin of exposure for inorganic arsenic [81]. The transfer of arsenic into the beverage also depends on processing. Rice water obtained by soaking unwashed rice in cold water for 30 min contained 2.8–4.8 ng/g of arsenic, whereas water obtained after boiling or soaking rice in hot water could exceed the permissible value of 10 ng/g if consumed regularly [78]. Therefore, whole grain or bran-rich formulations, which increase the content of bioactive compounds, may also increase arsenic exposure.

The use of filamentous fungal starters also requires the control of mycotoxins. In nuruk, a mixed starter used for Korean alcoholic beverages, 14 of 61 samples exceeded the Korean permissible level of 15 ppb of total aflatoxins, and some *Aspergillus* isolates produced aflatoxin B1, although the transfer of aflatoxins to the beverage was low (approximately 1.2–1.3%) [82]. Although these data refer to a starter for alcoholic beverages, they indicate that the purity of these starters, including the koji used for amazake, should be controlled. Microbiological quality is also relevant, particularly in spontaneously fermented beverages. In spontaneously fermented red rice water, the microbial community was dominated by Proteobacteria (59.63%), including *Pantoea*, together with Firmicutes [55], whereas flavored fermented rice water produced under controlled conditions remained microbiologically stable for 30 days at 4 °C [37]. In commercial makgeolli, an alcoholic rice beverage, *Bacillus cereus* was isolated from 58.1% of the products at low levels, and its detection rate was not significantly lower in pasteurized products [83]. These findings indicate that RBBs require controlled starters, hygienic processing and validated heat treatments.

4. Potential Health Effects of Non-Fermented and Fermented Rice-Based Beverages

The health-related evidence on RBBs derives mainly from in vitro, cell-based and animal studies, whereas human studies are scarce and have limited sample sizes (Table 5). In this section, the evidence is presented by rice variety and, within each variety, from in vitro and cell-based studies to animal and human studies.

4.1. Modulation of Gut Function and Gut Microbiota

The modulation of the intestinal ecosystem by RBBs varies based on the rice variety, the processing and the presence of live microorganisms or their metabolites. However, the presence of live microorganisms does not make a beverage a probiotic, as this term requires defined strains with a demonstrated health benefit in the host, and specific requirements also apply to the terms prebiotic, synbiotic and postbiotic [84–87]. In the case of white rice beverages, an in vitro bacterial growth assay showed that the growth of *Lactiplantibacillus plantarum* with jasmine rice amazake was similar to that obtained with glucose and higher than with isomaltooligosaccharides, without effects on *Escherichia coli* [54]. The LAB consortia present in a fermented rice beverage survived simulated gastrointestinal digestion (INFOGEST 2.0) better than in tiger nut or carob beverages [32]. In HT-29 colon cells, naturally fermented rice water upregulated the gene expression of monocarboxylate transporters 1 and 2, related to nutrient absorption, and of the tight junction proteins occludin and zonula occludens-1, related to barrier integrity [40]. In mice, koji amazake produced by double saccharification modified the structure of the caecal microbiota compared with phosphate-buffered saline [53]. Freeze-dried black koji amazake, added to a Western diet of mice, increased colonic occludin and faecal immunoglobulin A, whereas both black and yellow koji amazake decreased serum endotoxin [51].

In humans, evidence on white rice beverages focuses on koji amazake. In a randomized, placebo-controlled, double-blind parallel-group trial in 44 healthy adults with 2–5 defecations per week, a daily intake of 118 g of koji amazake for 4 weeks increased weekly defecation frequency (5.09 vs. 3.95 days at 4 weeks) and faecal weight compared with a non-fermented rice syrup, a response attributed to the presence of approximately 300 mg of *A. oryzae* cells per serving [52]. In this trial, koji amazake decreased the relative abundance of *Blautia* and increased that of *Bacteroides*, without differences in faecal short-chain fatty acids [52]. Pilot studies without a control group in patients with severe motor and intellectual disabilities ($n = 10$ and $n = 12$) reported reduced constipation scores and changes in Lactobacillales, *Escherichia-Shigella* and *Bifidobacterium* after 35 g/day intake of

malted rice amazake for 6 weeks, and these changes disappeared 6 weeks after the intake stopped [75,88]. In older inpatients and residents, the same product increased gut microbiota α-diversity and decreased *Desulfovibrio* [89]. In a randomized, double-blind trial in 60 overweight patients with irritable bowel syndrome, both a rice and rice bran drink fermented with *L. plantarum* JSA22 and its non-fermented counterpart improved global symptoms, and only abdominal bloating improved more with the fermented drink [64]. However, both drinks contained rice bran, so these effects cannot be attributed to the rice beverage alone.

The gut modulatory potential of brown rice beverages has been evaluated in a single human trial involving Okinawan adults with metabolic syndrome [35]. In this 4-week study, 40 participants were randomly allocated to consume daily 350 g of brown rice amazake or white rice amazake as a replacement for their main meal, without a placebo group. Consumption of the brown rice variant led to an increase in three bacterial taxa of the Clostridia class associated with short-chain fatty acid production (Lactobacillales bacterium DJF B280, butyrate-producing bacterium A2-207 and Firmicutes bacterium DJF VP44), whereas no differences were observed in α- or β-diversity, plasma short-chain fatty acids, or anthropometric, clinical and biochemical parameters [35]. The authors suggested that γ-oryzanol, which was more abundant in the brown rice beverage, could be transformed into ferulic acid by species such as those of *Clostridium* cluster IV, which were elevated in this group; however, the white rice group included more participants with type 2 diabetes, which may have influenced the results [35]. Lange and Nakamura [8] suggested that these changes could favor immune tolerance and reduce inflammation, but no immune or inflammatory outcome was measured in this trial.

For pigmented rice beverages, gut-related evidence is limited to a murine model of chemically induced colitis, in which purple rice drink kefir reduced serum tumor necrosis factor-α (TNF-α) ([50], Section 4.2). Studies on traditional pigmented rice beers, such as apong, have reported differences in the gut microbiota of regular drinkers [90,91], but these cross-sectional data refer to alcoholic beverages, may be confounded by diet, alcohol intake and other lifestyle factors, and were therefore not included in this review. Overall, the human evidence on gut function is restricted to koji amazake and to one LAB-fermented rice drink, and the reported microbiota changes should be interpreted as microbiota outcomes rather than as established health benefits (Table 5).

Table 5. Health-related evidence on rice-based beverages, ordered by rice variety and, within each variety, from in vitro to human studies.

Section	Rice Variety	Beverage	Level of Evidence	Design and Dose	Main Findings	Reference
4.1. Gut function and gut microbiota						
4.1	White	Jasmine rice koji amazake (F) vs. non-fermented rice	In vitro (bacterial growth)	Amazake in MRS broth, 48 h; glucose and isomaltooligosaccharide controls	*L. plantarum* growth similar to glucose and higher than with isomaltooligosaccharides; no effect on *E. coli*	[54]
4.1	White	LAB-fermented rice beverage (F)	In vitro digestion	Static gastrointestinal digestion (INFOGEST 2.0) of the fermented beverage	Lower loss of LAB in the rice beverage than in tiger nut or carob beverages	[32]
4.1	White and red	Fermented rice water (F)	Cell-based (HT-29)	Reconstituted fermented rice water (1×–10×), 24 and 48 h	Upregulation of MCT-1, MCT-2, occludin and ZO-1 gene expression	[40]
4.1	White	Koji amazake by double saccharification (F)	Animal (C57BL/6 mice, 6 per group)	200 µL/day, 14 days; PBS control	Changes in caecal β-diversity and in three species	[53]
4.1	White	Black and yellow koji amazake, freeze-dried (F)	Animal (mice on Western diet, 4 per group)	10% of feed, 2 months	Black koji: ↑ occludin and faecal IgA; both: ↓ serum endotoxin	[51]
4.1	White	Koji amazake (F)	Human RCT (44 healthy adults)	118 g/day, 4 weeks; non-fermented rice syrup placebo	↑ Defecation frequency and faecal weight; ↓ *Blautia*, ↑ *Bacteroides*; no change in faecal SCFA	[52]
4.1	White	Malted rice amazake (F)	Human, uncontrolled (10 and 12 patients with disabilities)	35 g/day, 6 weeks	↓ Constipation score; microbiota changes that reverted after stopping intake	[75,88]
4.1	White	Malted rice amazake (F)	Human, uncontrolled (13 older adults)	35 g/day, 6 weeks	↑ α-diversity; ↓ *Desulfovibrio*	[89]

Table 5. *Cont.*

Section	Rice Variety	Beverage	Level of Evidence	Design and Dose	Main Findings	Reference
4.1	Brown	Brown vs. white rice amazake (F)	Human, randomized without placebo (40 adults with MetS)	350 g/day, 4 weeks	↑ Clostridia species; no differences in diversity, plasma SCFA or clinical parameters	[35]
4.1/4.2	Pigmented (purple)	Rice drink kefir (F)	Animal (rats with chemically induced colitis)	150 mg/kg/day, 14 day, orally; PBS, prednisolone and cow's milk kefir controls	↓ Serum TNF-α vs. PBS, similar to prednisolone	[50]
4.2. Antioxidant, anti-inflammatory and immunomodulatory effects						
4.2	White	LAB-fermented and unfermented rice beverage	In vitro digestion (INFOGEST 2.0)	Static gastrointestinal digestion; beverages before and after digestion	TEAC ↑ 101.9-fold (fermented) and 30.7-fold (unfermented) after digestion; phenolic retention ~8%	[70]
4.2	White (commercial)	Commercial rice drink (NF)	Cell-based (Caco-2)	Volume of beverage equivalent to 25 µg/mL of its lipid fraction + LPS 1 µg/mL, 48 h	Lower antioxidant capacity and ROS reduction than bovine and goat milks	[92]
4.2	White	Unfermented and LAB-fermented rice beverage, digested	Cell-based (differentiated Caco-2 + LPS)	Bioaccessible fraction (1:15 *v*/*v*), 24 h, then LPS 10 µg/mL, 24 h	Unfermented: ↓ IL-6, IL-8 and NO, lost after fermentation; both ↓ ROS; no TEER recovery	[93]
4.2	White	Black and yellow koji amazake (F)	Animal (mice on Western diet)	10% of feed, 2 months	Black koji: ↑ Nrf2, HO-1, SOD-2; both: ↓ hepatic MCP-1	[51]
4.2	Pigmented (black, red, brown)	Fermented rice water (F)	In vitro digestion	Static gastrointestinal digestion (INFOGEST)	Highest polyphenol bioaccessibility in black rice (75.25%)	[37]

Table 5. *Cont.*

Section	Rice Variety	Beverage	Level of Evidence	Design and Dose	Main Findings	Reference
4.2	Pigmented (Riceberry) vs. white	Koji amazake (F), ethanol extracts	Cell-based (RAW 264.7)	25–500 µg/mL for 24 h, then H2O2 350 µM, 3 h; 25–500 µg/mL for 1 h, then LPS 1 µg/mL, 24 h	Riceberry: stronger cytoprotection and ↓ NO, TNF-α and IL-6	[36]
4.2	Pigmented (Riceberry)	Amazake fermented with *P. acidilactici* FSPO-PJ1 vs. conventional amazake (F)	Cell-based (RAW 264.7 + LPS)	10 mg/mL for 1 h, then LPS 1 µg/mL, 24 h	NO inhibition 46.07% vs. 40.86%	[66]
4.2	Pigmented (Sinlek) vs. white	Iron rice hydrolysate drink (NF)	Human, non-randomized (100 older adults)	100 mL/day, 30 days	↑ Serum antioxidant activity in all groups, including the white rice drink	[94]
			4.3. Metabolic and nutritional effects			
4.3	White	Koji amazake (F) vs. rice hydrolysate without koji	Human, randomized crossover (18 healthy adults) + ex vivo (everted rat intestinal sacs)	Single intake of 118 g or 39 g; glucose and insulin over 120 min	↓ Postprandial glucose and insulin; ↓ glucose absorption in everted rat sacs	[31]
4.3	Not specified	Koji amazake (F)	Human RCT (20 participants)	160 g/day, 4 weeks; placebo	↓ Systolic blood pressure; ACE inhibition in vitro	[30]
4.3	White	Malted rice amazake (F)	Human, uncontrolled (13 older adults)	35 g/day, 6 weeks	↑ GNRI and serum albumin	[89]
4.3	Brown	Brown vs. white rice amazake (F)	Human, randomized without placebo (40 adults with MetS)	350 g/day, 4 weeks	No differences in anthropometric, clinical or biochemical parameters	[35]

Table 5. *Cont.*

Section	Rice Variety	Beverage	Level of Evidence	Design and Dose	Main Findings	Reference
4.3	Pigmented (Sinlek) vs. white	Iron rice hydrolysate drink (NF)	Human, non-randomized (100 older adults)	100 mL/day, 30 days	↑ Hemoglobin and MCHC only in anemic subjects; ↓ serum iron in this group	[94]
4.4. Antiproliferative potential						
4.4	White	Unfermented and LAB-fermented rice beverage, digested	Cell-based (Caco-2)	1:15 *v*/*v*, 24 h	Cell viability 71.9% (unfermented) vs. 90.2% (fermented)	[95]

No animal or human study on the antiproliferative or chemopreventive effects of rice-based beverages was identified. ↑ increase; ↓ decrease. ACE: angiotensin-converting enzyme; F: fermented; GNRI: Geriatric Nutritional Risk Index; HO-1: heme oxygenase-1; IgA: immunoglobulin A; IL: interleukin; LAB: lactic acid bacteria; LPS: lipopolysaccharide; MCHC: mean corpuscular hemoglobin concentration; MCT-1/2: monocarboxylate transporters 1 and 2; MCP-1: monocyte chemotactic protein-1; MetS: metabolic syndrome; NF: non-fermented; NO: nitric oxide; Nrf2: nuclear factor erythroid 2-related factor 2; ORAC: oxygen radical absorbance capacity; PBS: phosphate-buffered saline; RCT: randomized controlled trial; ROS: reactive oxygen species; SCFA: short-chain fatty acids; SOD-2: superoxide dismutase-2; TEAC: Trolox equivalent antioxidant capacity; TEER: transepithelial electrical resistance; TNF-α: tumor necrosis factor-α; TSP: total soluble polyphenols; ZO-1: zonula occludens-1.

4.2. Antioxidant, Anti-Inflammatory and Immunomodulatory Effects

The antioxidant, anti-inflammatory, and immunomodulatory properties of RBBs depend on the rice variety used and on the changes occurring during fermentation and simulated digestion, and most of this evidence derives from chemical, cell-based and animal studies [70,93].

White rice beverages generally contain the lowest levels of native polyphenols, and the effects of fermentation and simulated digestion on their antioxidant capacity measured with chemical assays are described in Section 3.2. In Caco-2 cells, a commercial rice drink showed lower antioxidant capacity and a lower reduction in reactive oxygen species than bovine and goat milks [92]. In lipopolysaccharide-stimulated Caco-2 cells, the bioaccessible fraction of the unfermented rice beverage obtained after simulated gastrointestinal digestion (INFOGEST 2.0) reduced interleukin (IL)-6 (33.7%), IL-8 (46.0%) and nitric oxide (19.0%), but these effects were lost after fermentation, while both beverages reduced intracellular reactive oxygen species and neither restored transepithelial electrical resistance [93]. In mice fed a Western diet, black koji amazake increased the colonic expression of nuclear factor erythroid 2-related factor 2, heme oxygenase-1 and superoxide dismutase-2, and both black and yellow koji amazake reduced hepatic monocyte chemotactic protein-1 [51]. In humans, no trial has measured antioxidant or inflammatory biomarkers after the intake of white rice beverages.

Brown rice beverages retain the bran layer, which contains γ-oryzanol, vitamin E (tocopherols) and phenolic acids [3]. However, among the included studies, no cell-based, animal or human study evaluated the antioxidant or anti-inflammatory effects of a brown rice beverage. Evidence on fermented brown rice as a grain, such as the reduction in serum TNF-α, IL-6 and IL-1β in rats with chemically induced colorectal carcinogenesis fed *Lactobacillus acidophilus*-fermented germinated brown rice [96], refers to a solid product and cannot be extrapolated to beverages. Likewise, fermentation with LAB and enzymatic hydrolysis increased the total phenolics and antioxidant activity of aqueous solutions obtained from rice bran [97], a by-product that does not represent the beverage.

Pigmented rice beverages showed the highest antioxidant activity in chemical assays (Section 3.2). In vitro, black fermented rice water also showed the highest polyphenol bioaccessibility (75.25%) after simulated digestion [37]. In RAW 264.7 macrophages, ethanol extracts of Riceberry amazake showed stronger protection against H_2O_2-induced oxidative stress and a stronger inhibition of nitric oxide, TNF-α and IL-6 after lipopolysaccharide stimulation than extracts of Japanese white rice amazake [36]. LAB fermentation of Riceberry amazake with *Pediococcus acidilactici* FSPO-PJ1 increased nitric oxide inhibition from 40.86% to 46.07% [66]. In rats with chemically induced colitis, purple rice drink kefir reduced serum TNF-α compared with the negative control, with values similar to those obtained with prednisolone and cow's milk kefir [50]. In humans, elderly subjects who consumed a Sinlek iron rice drink for 30 days showed increased serum antioxidant activity, but this increase was also observed with a white rice drink, and the study was not randomized [94].

Beyond direct antioxidant activity, fermented RBBs have been described as sources of live microorganisms and metabolites with potential immunomodulatory activity [57,98,99]. However, high LAB counts, such as the >8 log CFU/mL reported in fermented rice water [37], do not demonstrate a probiotic or immunomodulatory effect [84], and no included human study measured immune outcomes. Therefore, the immunomodulatory potential of RBBs remains to be confirmed.

4.3. Metabolic Effects

The metabolic effects of RBBs are influenced by the specific grain variety and by the changes induced by processing. White rice beverages primarily serve as sources of rapid

energy due to their high starch and carbohydrate content [42,52]. In vitro, water and ethanol extracts of koji amazake inhibited angiotensin-converting enzyme [30]. Ex vivo, glucose absorption from koji amazake was lower than from a glucose solution in everted rat intestinal sacs [31]. In humans, koji amazake (118 g or 39 g) suppressed the postprandial increase in blood glucose and insulin compared with a hydrolysate of the same rice prepared without koji in a randomized, single-blind crossover study in 18 healthy adults [31]. In a randomized, double-blind, placebo-controlled trial in 20 participants, a daily intake of 160 of koji amazake for 4 weeks decreased systolic blood pressure without changes in diastolic blood pressure or pulse [30]. In older patients and residents at risk of malnutrition, malted rice amazake increased the Geriatric Nutritional Risk Index and serum albumin after 6 weeks, although the study had no control group and a high drop-out rate [89]. In contrast, no changes in metabolic blood tests were observed after a LAB-fermented rice and rice bran drink in overweight patients with irritable bowel syndrome [64].

Brown rice beverages retain the bran layer, which is rich in fiber, vitamins, and phytosterols [35,38]. In mice fed a high-fat diet, brown and germinated brown rice showed a low glycemic index and reduced the signs of obesity and fatty liver compared with other rice varieties [100]; however, these data refer to rice grains and not to beverages. In adults with metabolic syndrome, the daily consumption of brown rice amazake for 4 weeks did not change anthropometric, clinical or biochemical parameters compared with white rice amazake, although some of the gut microbiota species that increased were negatively correlated with triglyceride levels [35]. Therefore, the metabolic benefits attributed to brown rice beverages are not yet supported by human data.

Pigmented rice varieties contain anthocyanins and proanthocyanidins, and extracts of black and red rice reduced blood glucose and triglyceride levels in diabetic rats after eight weeks [101]; however, these results refer to grain extracts and not to beverages. Among the included beverage studies, the only human study was conducted in elderly subjects who consumed a Sinlek iron rice drink for 30 days. Hemoglobin and mean corpuscular hemoglobin concentration increased only in the anemic group, whereas serum iron and transferrin saturation decreased in this group, and body weight and nutrition scores increased in non-anemic subjects who received the higher iron dose [94]. This study was not randomized; the anemic group had no control, and the iron dose reported per serving differs from that reported for the same drink in a previous study [47]. Studies on traditional pigmented rice beverages with alcohol, such as apong or sato, were not included because of their alcohol content [10,91,102,103].

Germination can increase the GABA content of RBBs [48,68], and germination combined with LAB fermentation produced a GABA-enriched brown rice beverage, although glutamate was added as a precursor [104]. GABA is a non-protein amino acid that acts as an inhibitory neurotransmitter and has been associated with stress reduction and blood pressure regulation [104]. However, no included study evaluated the effects of GABA from RBBs in cells, animals or humans, and the amounts provided by the beverages vary widely, from 0.17 mg per 150 mL in a germinated black glutinous rice drink to 271.53 mg/100 g (dry weight) in germinated rice amazake [68,76].

4.4. Antiproliferative and Chemopreventive Potential: Preclinical Evidence

The exploration of the antiproliferative potential of RBBs is an emerging field characterized by significant scientific gaps, as the available evidence is restricted to cell models [95]. Antiproliferative activity in cancer cell lines does not translate directly into chemopreventive or therapeutic efficacy in humans, and the evidence is therefore presented according to the experimental level.

4.4.1. Cell-Based Studies

Among the included studies, only one evaluated the antiproliferative activity of a rice beverage itself. After simulated gastrointestinal digestion, the bioaccessible fraction of an unfermented white rice beverage reduced Caco-2 colorectal adenocarcinoma cell viability to 71.9%, induced early apoptosis in 59.1% of the cells and showed selectivity towards cancer cells compared with non-tumoral CCD-18Co colon cells [95]. In the same study, lactic acid fermentation enhanced the antiproliferative activity of the tiger nut beverage and induced cell cycle arrest with the carob beverage, but did not enhance that of the rice beverage (90.2% viability after fermentation), an effect associated with the microbial degradation of *p*-coumaric acid [70], a phenolic compound with antiproliferative activity in colorectal cancer cells [95]. In addition, a chloroform fraction of white rice water fermented for 24 h reduced the viability of HepG2 hepatocellular carcinoma cells in a dose-dependent manner, from 49.41% at 125 µg/mL to 29.68% at 1000 µg/mL [105]. However, this fraction does not represent the beverage and also contained non-phenolic compounds, and as non-tumoral cells were not tested, it cannot be established whether this effect was selective for cancer cells or reflected a general cytotoxicity.

For brown and pigmented rice beverages, no cell-based study was identified, and the available data refer to grain fractions or isolated compounds. A proanthocyanidin-rich fraction from red rice reduced the migration and invasion of MDA-MB-231 breast cancer cells [106]. Similarly, a proanthocyanidin-rich fraction from red rice germ and bran induced cell cycle arrest and apoptosis in HepG2 cells [107]. In black rice, cyanidin-3-glucoside and peonidin-3-glucoside selectively inhibited the proliferation of HER2-positive breast cancer cells [108]. Peonidin-3-glucoside also inhibited lung cancer cell metastasis by down-regulating proteinase activities and the mitogen-activated protein kinase pathway [109]. These findings suggest mechanisms by which pigmented RBBs might act, but whether these compounds reach active concentrations in the beverages and after digestion has not been tested.

4.4.2. Animal and Human Evidence

No animal or human study has evaluated the antiproliferative or chemopreventive effects of an RBB. The closest evidence comes from male F344 rats with 1,2-dimethylhydrazine/dextran sulfate sodium-induced colorectal carcinogenesis, in which diets containing germinated brown rice (10%) or germinated brown rice fermented with *Lactobacillus acidophilus* (2.5–10%) for 10 weeks reduced the number of aberrant crypt foci, a preneoplastic lesion, and serum TNF-α, IL-6 and IL-1β [96]. Only the lowest dose of the fermented product (2.5%) reduced sialomucin-producing aberrant crypt foci and increased the pro-apoptotic proteins Bax and cleaved caspase-3 [96]. However, the fermented product was a solid grain incorporated into the diet, so these results cannot be extrapolated to beverages.

4.4.3. Limitations and Translational Relevance

The available evidence is limited to a single cell model for a rice beverage and to studies of grain fractions or isolated compounds, most of which tested undigested samples at concentrations that may not be reached in the intestine after the consumption of the beverage. In addition, in the only study with RBBs, fermentation reduced the antiproliferative activity of the rice beverage, whereas it enhanced that of the tiger nut beverage and induced cell cycle arrest with the carob beverage tested in parallel, indicating a matrix-dependent effect [95]. Therefore, these findings should be described as preclinical evidence from cell models, and the evidence remains insufficient to establish chemopreventive or clinical efficacy.

An overview of the reported effects and of the level of evidence supporting them is illustrated in Figure 3 and summarized in Table 5.

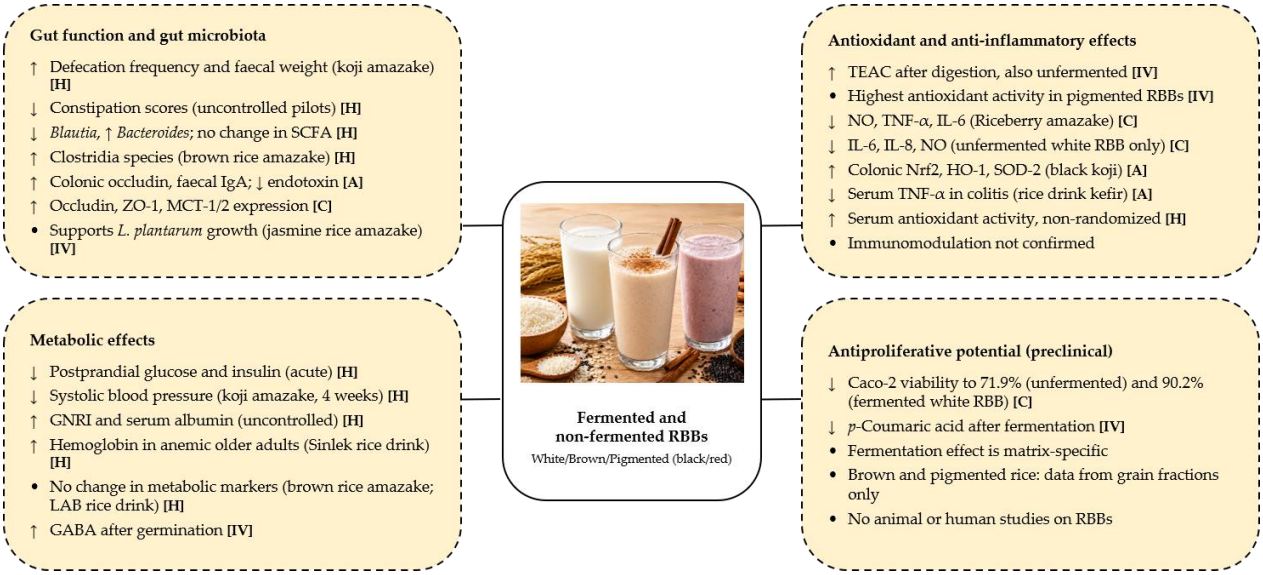

Figure 3. Main reported effects of fermented and non-fermented rice-based beverages (RBBs) and level of evidence supporting them. ↑ increase; ↓ decrease; Level of evidence: [IV] in vitro (composition, chemical assays or simulated digestion); [C] cell-based; [A] animal; [H] human. GABA: γ-aminobutyric acid; GNRI: Geriatric Nutritional Risk Index; HO-1: heme oxygenase-1; IgA: immunoglobulin A; IL: interleukin; LAB: lactic acid bacteria; MCT-1/2: monocarboxylate transporters 1 and 2; NO: nitric oxide; Nrf2: nuclear factor erythroid 2-related factor 2; RBBs: rice-based beverages; SCFA: short-chain fatty acids; SOD-2: superoxide dismutase-2; TEAC: Trolox equivalent antioxidant capacity; TNF-α: tumor necrosis factor-α; ZO-1: zonula occludens-1.

5. Limitations

This review has some limitations that should be acknowledged. Only PubMed and Scopus were searched and the search was restricted to 2016–2026, so relevant studies indexed in other databases, published earlier or available only as grey literature may not have been retrieved; however, this period was chosen to provide a comprehensive overview of the most recent decade of research, which was the aim of this review. In addition, screening and data extraction were performed by a single researcher, which may have increased the risk of selection and extraction errors. Another limitation is the heterogeneity of the included beverages in rice variety, formulation, dilution and processing. In addition, the experimental designs are also heterogeneous, and most of the evidence derives from compositional, in vitro digestion, cell-based and animal studies, whereas human studies were scarce, with limited sample sizes, short intervention periods and often no control group. The doses and durations of the interventions also differed widely. Because of this heterogeneity, no meta-analysis was performed and the findings were synthesized narratively. In addition, the design of the available studies does not always allow causal relationships between the consumption of RBBs and the reported effects to be established. Finally, no formal risk-of-bias assessment was performed, although limitations of studies have been identified and accounted for throughout the manuscript.

6. Conclusions and Future Perspectives

The current scientific landscape defines RBBs as a heterogeneous category of beverages whose composition and potential health effects depend on the rice variety, the processing and the microorganism employed. While non-fermented variants offer immediate nutritional value, mainly as a source of carbohydrates, their protein, iodine and polyphenol contents are generally low. Compared with white rice, pigmented, whole and germinated rice increase

the phenolic, γ-oryzanol and GABA contents of the beverages. Furthermore, fermentation can increase some compounds, such as free amino acids and B vitamins, as well as the release of minerals in vitro. However, fermentation does not universally improve the functional properties of RBBs, as in some studies it decreased antioxidant activity and, in cell models, it reduced the antiproliferative and cytokine-modulating activity of a white rice beverage. Similarly, the increases in antioxidant capacity observed after simulated digestion occurred with and without fermentation and were measured only with in vitro assays. The human evidence derives from few trials with limited sample sizes, which suggest effects on bowel function, gut microbiota composition, postprandial glycemia and systolic blood pressure, whereas antioxidant, anti-inflammatory and antiproliferative effects remain preclinical.

Moving forward, several critical gaps must be addressed to transition from preclinical findings to clinical evidence. Future research should prioritize adequately powered, randomized controlled human trials with appropriate non-fermented comparators to confirm the effects observed in the available trials and to evaluate the outcomes suggested by animal and in vitro models. From a technological perspective, the next frontier lies in the design of tailored starter cultures utilizing characterized strains to achieve metabolic precision, optimize bioactivity, and ensure process standardization, together with food safety control (arsenic, mycotoxins and microbiological quality). Additionally, exploring the interaction between RBBs and the host's gut microbiota profile may open the door for personalized nutrition strategies. Ultimately, cross-disciplinary efforts coupling advanced metabolomics with green food processing will be essential to define the potential of RBBs in modern diets.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/foods15224055/s1. Table S1: Characteristics of the primary studies included in the review ($n = 45$).

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Abbreviations

The following abbreviations are used in this manuscript:

ACE	Angiotensin-converting enzyme
DPPH	2,2-diphenyl-1-picrylhydrazyl
F	Fermented
GABA	γ-aminobutyric acid
GAE	Gallic acid equivalents
GM	Genetically modified
GNRI	Geriatric Nutritional Risk Index
HepG2	Human hepatocellular carcinoma cells

HO-1	Heme oxygenase-1
IgA	Immunoglobulin A
IL	Interleukin
LAB	Lactic acid bacteria
LPS	Lipopolysaccharide
MCHC	Mean corpuscular hemoglobin concentration
MCP-1	Monocyte chemotactic protein-1
MCT-1/2	Monocarboxylate transporters 1 and 2
MetS	Metabolic syndrome
NF	Non-fermented
NO	Nitric oxide
Nrf2	Nuclear factor erythroid 2-related factor 2
ORAC	Oxygen radical absorbance capacity
PBS	Phosphate-buffered saline
PG	Pigmented rice variety
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RBBs	Rice-based beverages
RCT	Randomized controlled trial
ROS	Reactive oxygen species
SCFA	Short-chain fatty acids
SDGs	Sustainable Development Goals
SOD-2	Superoxide dismutase-2
TAC	Total anthocyanin content
TEAC	Trolox equivalent antioxidant capacity
TEER	Transepithelial electrical resistance
TFC	Total flavonoid content
TNF-α	Tumor necrosis factor-α
TPC	Total phenolic content
TSP	Total soluble polyphenols
ZO-1	Zonula occludens-1

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