beverages

MDPI

Review

Beyond Market Growth: Are Plant-Based Beverages Nutritionally and Technologically Suitable Alternatives to Cow's Milk?

Francine Pimentel de Andrade [1,2], Wanderson dos Santos Carneiro [1], José Matheus Santos-Silva [2], Anabela Raymundo [2] and Carlos Eduardo de Farias Silva [1,*]

[1] Technology Center, Federal University of Alagoas, Maceió 57072-970, Alagoas, Brazil; francine.fpa@gmail.com (F.P.d.A.); eqwanderson@gmail.com (W.d.S.C.)
[2] LEAF—Linking Landscape, Environment, Agriculture and Food Research Center, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal; jmatheussilva@isa.ulisboa.pt (J.M.S.-S.); anabraymundo@isa.ulisboa.pt (A.R.)
* Correspondence: carlos.eduardo@ctec.ufal.br; Tel.: +55-(82)-99309-8572

Abstract

Changes in consumer behavior have intensified the demand for alternative protein sources, driving changes in food consumption patterns. At the same time, the increasing consumer awareness considering the health and environmental impacts in food systems, has stimulated interest in more functional and sustainable products. In this context, plant-based beverages (PBBs) have gained attention as potential alternatives to milk. This study was aimed at evaluating plant-based beverages as alternatives to cow's milk, focusing on their nutritional composition, environmental impact, and technological challenges. Although cow's milk has a high biological value and nutritional density, plant-based beverages present variable compositions, generally with lower levels of protein and minerals. However, they stand out for the presence of bioactive compounds and have a nutritional quality which can be improved through fortification strategies. From an environmental perspective, their production is associated with a substantially lower carbon footprint compared to dairy farming. Despite these advantages, the sector still faces technological challenges related to physicochemical stability and sensory acceptance due to complex residual flavors. This review highlights the need for improvements in terms of manufacturing processes and regulatory frameworks to establish these beverages as safe, nutritious, and sustainable options in the global market.

Keywords: dairy alternatives; sustainability; vegetarian; vegan and flexitarian diet

Check for updates

Academic Editor: Petko Denev

Received: 31 March 2026
Revised: 2 June 2026
Accepted: 5 June 2026
Published: 15 June 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Milk and dairy products are among the most widely consumed foods worldwide, mainly due to their high nutritional value and the presence of proteins of high biological quality [1]. However, the increasing consumer interest in dietary diversification, lactose-free products, animal welfare and environmental sustainability has stimulated the development of alternative protein sources, particularly plant-based products [2,3]. In this scenario, plant-based beverages (PBBs) have emerged as a dynamic and expanding category, characterized by a wide diversity of raw materials, technological processes, and nutritional profiles [4].

Several factors such as lactose intolerance, milk protein allergies and the increasing adoption of vegan and flexitarian dietary patterns have contributed to the growing consumption of plant-based beverages [5,6]. However, some studies have shown that these

products often present lower nutritional profiles compared to dairy milk, particularly in terms of protein and mineral contents [5–8]. For example, Pointke et al. [8] evaluated the micronutrient composition and sensory properties of almond-, oat-, and soy-based beverages in comparison with cow's milk and reported that plant-based beverages did not show nutritional and sensory equivalence to cow's milk. Nevertheless, when properly fortified with essential nutrients, their nutritional quality can be significantly improved, making them viable alternatives to animal-derived products [9]. For instance, to achieve the same protein intake provided by 1 L of cow's milk, approximately 13% more soy beverage must be consumed [10]. However, plant raw materials are naturally rich in bioactive compounds, including dietary fiber, unsaturated fatty acids and antioxidants, which may provide functional and health-related benefits, and this can help consumers' acceptance of PBBs [11].

The environmental footprint of food products is commonly expressed as carbon dioxide equivalent (CO_2-eq). Comparisons based on CO_2-eq per functional unit indicate that cow's milk is generally associated with higher greenhouse gas emissions than plant-based beverages, which, in some cases, are several times greater. These values may vary depending on farm management, production systems, processing conditions, and other input variables [12–14]. Furthermore, life cycle assessment (LCA) is widely recognized as the main tool used to systematically quantify and compare the environmental impacts related to the production of milk-derived beverages [15].

In this context, the present review aimed to analyze plant-based beverages (PBBs) as alternatives to cow's milk, addressing their classification and typology, as well as the main processing technologies involved in their production. This review also discussed the physicochemical, sensory and technological challenges associated with these products, and evaluated their nutritional profile together with the fortification strategies used to improve their nutritional equivalence compared to dairy beverages. In addition, aspects related to sustainability and environmental impacts were examined, along with current market trends and the main commercial products available. Finally, the current limitations and future perspectives for the development and consolidation of plant-based beverages were highlighted, contributing to the scientific and technological progress in this expanding research topic.

The literature selection was carried out applying the databases Scopus, Web of Science, ScienceDirect, and PubMed. The search was performed using keywords (alone and in combination) such as "plant-based beverages", "plant-based milk", "dairy alternatives", "fortification", "processing technologies", and "sustainability", prioritizing recent studies, while also considering relevant earlier references related to the scope of this review.

2. Dairy Beverages and the Shift to Plant-Based Beverages

The consumption of milk has been present throughout human existence. Historically, the introduction of this beverage as a common component of the human diet dates back to approximately 10,000 years ago [16], when early societies adopted animal husbandry practices, started the domestication of animals capable of producing milk, and began incorporating it as a beverage or in the form of different dairy products.

Firstly, milk is defined as a raw material of animal origin obtained from the mammary glands of female mammals [17], with cow's milk considered the default unless another animal source is specified. Consequently, it can be sourced from a wide range of species, including cows, sheep, goats, buffaloes, camels, and reindeer, among others. Each species produces milk with distinct compositional and sensory characteristics, contributing to differences in flavor [18] and other physicochemical and sensory functionalities [19]. Bovine milk represents the most consumed milk type worldwide, significantly contributing to

food security, supporting household incomes, and delivering essential nutrients. There are more than 6 billion people worldwide consuming milk and dairy products derived from different animal species [20], with annual *per capita* consumption reaching an estimated 87 L in 2023, representing an increase of 16% compared to 2013, according to the Food and Agriculture Organization of the United Nations (FAO) database [21].

Beyond its sensory attributes, milk is recognized as a valuable dietary resource due to its high nutritional value, becoming a fundamental component of everyday meals, either through direct consumption as a beverage or through its transformation into a variety of products. It is consolidated as an excellent source of protein, with values varying around 32% per liter and providing essential amino acids in addition to enhancing bioavailability [22]. Milk also contains polyunsaturated fatty acids (PUFA), including linoleic acid, α-linolenic acid, and conjugated linoleic acid, which have been associated with anticarcinogenic and antioxidant properties. Nevertheless, because milk fat is predominantly composed of saturated fatty acids, milk is not generally regarded as a major dietary source of PUFA [23]. In the United States, for instance, dairy products are considered a key dietary source of vitamin D, a nutrient essential for efficient intestinal absorption of calcium [24]. However, bovine milk is generally a limited source of vitamin D [25], with its contribution to dietary intake largely dependent on fortification practices [26]. In addition, milk naturally provides several essential nutrients, including vitamins A, B_2, B_5, B_6, and B_{12}, highlighting its overall nutritional relevance [12].

Among the benefits associated with this nutrient-rich liquid food, several physiological roles can be highlighted, including its contribution to bone formation [24], early-life gut development [27], cardiometabolic health [28], and others. Furthermore, removing milk from the diet can worsen existing nutrient deficiencies if it is not properly monitored and supported with suitable replacements or supplements [15].

Although these effects are well known, dairy consumption has declined in recent years due to consumer skepticism about its health effects, as highlighted by Hernández et al. [29]. Because of all concerns about animal-derived products through the eyes of sustainability, there is an emerging need for healthier and more sustainable alternatives. In this perspective, a shift in consumer behavior has been observed and increasingly fortified. This modification is characterized by a transition from animal-derived milk consumption, which has been widely consumed, recommended and valued for thousands of years, to the growing preference for plant-based alternatives [30]. That shift is closely associated with the adoption of sustainable practices, since plant-based proteins are expected to become essential when animal-derived proteins collapse in their role of feeding the demands of a growing world population, especially considering that animal production systems have limitations to be expanded (detailed in Section Drivers and Limitations Associated with Plant-Based Beverages (PBBs)) [31,32].

Drawing on and adapting the conceptual approaches of Sharma et al. [33], while incorporating complementary and concise aspects, the drivers of this consumption transition can be systematically classified into four main groups and are represented in Figure 1. They are: (I) sustainability and the offer of new nutrient sources; (II) veganism and vegetarianism adoption; (III) the rise of food intolerances and allergen concerns; and (IV) changes in consumer behavior and market tendencies.

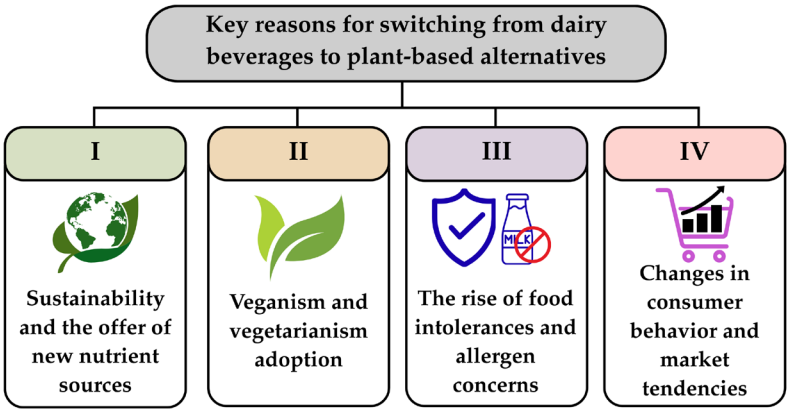


Figure 1. Key reasons considering the switch from dairy beverages to plant-based alternatives.

Drivers and Limitations Associated with Plant-Based Beverages (PBBs)

As outlined in Section 2, the adoption of plant-based beverages is linked with several benefits for individual health and environmental sustainability. In this review, the main reasons driving this behavior are organized into four major groups (Figure 1), each with its own advantages and limitations.

(I) Considering **environmental sustainability**, the production and processing of plant-based alternatives tend to generate a smaller environmental impact [34]. This may occur because greater consumption and production possibilities are associated with an increased contribution to sustainable practices. These pathways have the power to decrease the focus on the traditional culture of milk consumption, which requires (a) large areas for grazing and for feed crop growing [35]; (b) higher water consumption for the animals, feed cultivation and processing [36]; and (c) constant greenhouse gas emission, mainly from the significant amount of methane generation from cows' digestive systems [37] in comparison to plant cultivation. For these reasons, it is important and advantageous to expand the exploration of terrestrial resources, shifting beverage production from animal-based to plant-based raw materials.

Being the plant sources most frequently used for plant-based beverages, cereals, legumes, nuts, and seeds have been widely explored in recent years [38]. In comparison to conventional milk, these raw materials may not provide a complete nutritional profile [39], such as the lower levels of total essential amino acids in almond, coconut, and rice beverages compared to cow's milk (up to 40%), as well as the low protein content of almond and rice beverages and the high saturated fat content of coconut beverages [40], but they can offer other benefits and this must be considered for the specific plant source considered.

In this sense, each seed, cereal, nut, or legume used as a raw material for plant-based beverages presents a distinct nutritional profile. For instance, while oats are a notable source of beta-glucans, a class of soluble dietary fibers with high water-holding capacity, which are associated with cholesterol-lowering effects and reduction in markers of cardiovascular disease [41], almonds also contribute to cardiovascular health due to their content of unsaturated fatty acids and the significant levels of vitamin E with antioxidant activity [42], and a broad range of essential minerals.

(II) A significant driver of the growing consumption of plant-based alternatives is the increasing **adoption of vegan and vegetarian diets**. The motivations behind these practices are diverse but are predominantly associated with animal welfare concerns [43] or also allergies [44] and religious concepts [45]. Individuals following such dietary patterns rely on a wide range of food products from plant-based resources—including snacks, ready-to-eat meals and beverages.

As plant-based beverages do not provide the same nutritional profile as milk [46], vegan consumers—who avoid all animal-derived products—need to carefully select alternative raw materials to achieve a similar nutritional balance. Despite these limitations, the expansion of plant-based products has opened new opportunities for diversified nutrient intake, distinct nutritional profiles, and innovation in sensory and gastronomic experiences, with beverages playing a key role in broadening the diversity and functionality of the modern food landscape. Studies identifying early drivers of liking/disliking should be prioritized [47], with sensory quality alone being insufficient, as acceptance also depends on factors like price, familiarity, and perceived benefits.

(III) Looking at the possibilities for individuals with **milk intolerance and the growing wave of dairy food allergens**, plant-based beverages play a crucial role in providing suitable alternatives for these affected individuals [48]. Options such as oat, coconut, almonds, and soy-based drinks contribute to the dietary inclusion of people with dairy restrictions. While awareness of food-related allergic reactions was limited in the past, they are now recognized as a public health concern. The growing awareness of food allergies, together with the availability of non-allergenic plant-based beverages, contributes to their increasing acceptance and consumption [49]. The rise in allergic reactions and intolerances in recent years, whether related to milk protein or lactose [50], has driven the development of technologies for producing plant-based beverages. This trend may be linked to shifts in dietary patterns, physiological adaptation, or reduced lactose consumption driven by skepticism and unnecessary avoidance [51]. In this context, the Sustainable Development Goals (SDGs) [52] emphasize the importance of food safety and food security, ensuring access to safe and adequate nutrition for all individuals.

Despite their increasing popularity, plant-based beverages may raise concerns related to allergenicity and food intolerance depending on their botanical source and formulation. Soy-based beverages are among the most relevant cases, as soy proteins are recognized as major food allergens in many countries. Similarly, beverages derived from tree nuts, such as almond or hazelnut, may trigger allergic reactions in sensitized individuals, while legume-based products can also present risks of cross-reactivity. In addition, certain plant-based beverages may contain fermentable carbohydrates, gluten traces, or food additives capable of inducing intolerance-related gastrointestinal symptoms in susceptible consumers. Therefore, although these products are frequently perceived as healthy alternatives to dairy milk, their safety and suitability should be evaluated according to individual nutritional and clinical conditions [53–55].

(IV) Lastly, **changes in consumer behavior**, together with evolving new market dynamics, support the rationale for the growing adoption of plant-based products [56]. This trend is associated with both advantages and limitations, placing on one side the perceived health benefits, the environmental sustainability, and the product diversification, and on the other hand, challenges related to nutritional adequacy, sensory acceptance, and food neophobia related to the hesitation to ingest new foods or drinks [57].

Two notable examples were provided by the Innova Market Insights 2026 survey, which annually identifies the top 10 food trends, with the keyword "Beverages with Purpose" ranked in fourth position, highlighting beverages as drivers of wellness and innovation, and "Authentic Plant-Based" ranked in fifth position, emphasizing the increasing consumer preference for natural plant-based proteins and their associated benefits [58]. This transition to plant-based is driven by dietary trends, benchmarking, and health influences shaping consumer choices, with the sustained adoption of plant-based products still presenting several challenges. Understanding the characteristics, innovations and limitations of PBBs based on recent studies is extremely necessary.

3. Classification and Typology of Plant-Based Beverages

Plant-based beverages (PBBs) include a wide range of products obtained from different plant sources. These beverages are commonly grouped according to the main raw material used. The most widely used classification is based on botanical species [59–62], including legumes, nuts, cereals, seeds, tubers, and coconut. The main types of plant-based raw material applied for beverage production are shown in Figure 2.

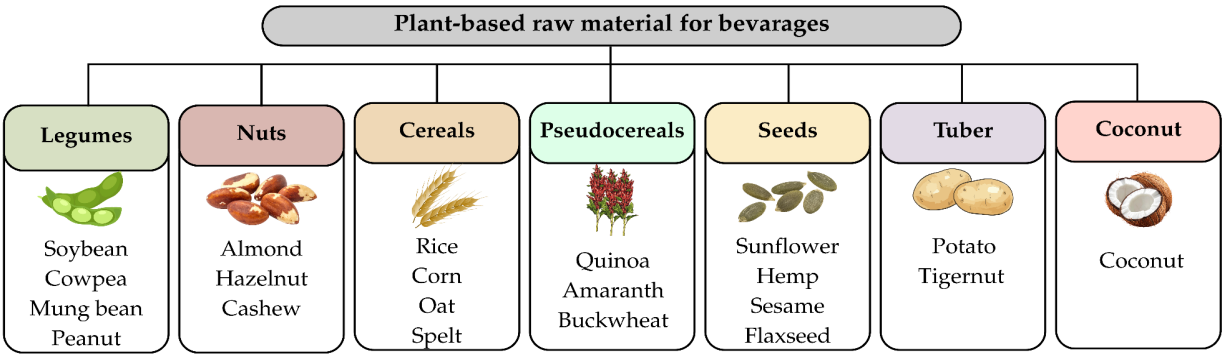


Figure 2. Classification of plant-based raw materials used for plant-based beverages. Based on previous studies [59–62].

Due to the wide diversity of plant sources explored for the development of plant-based beverages and related products, different raw materials have been investigated as bases for plant-based milk systems. Representative examples reported in the recent literature are summarized in Table 1. In addition to beverages obtained from a single plant source, the literature also reports formulations prepared using mixtures of different plant materials. The selection of one or more ingredients directly influences the nutritional composition and functional characteristics of the final product [7].

Table 1. Plant-based sources used in the literature for the development of plant-based beverages and beverage-derived products (2020–2026).

Raw Material	Objective	Reference
Almond, cashew and macadamia	Evaluation of the fermentation potential of lactic acid bacteria isolates from herbs, fruits, and vegetables as starter cultures for nut-based dairy alternatives	[63]
Brazil nut and macadamia	Development and characterization — the color, proximate composition, microbiological and sensorial quality to determine its shelf life were evaluated	[64]
Cashew, hazelnut, peanut, walnut, and almond	Production of nut-based milks and kefir beverages and their characterization through selected physicochemical analyses	[65]
Chickpea	Development and characterization of a fermented beverage obtained through co-fermentation with strains of lactic acid bacteria and yeast	[66]
Chickpea and coconut	Combination of different concentrations of chickpea and coconut extracts. Chemical composition analyzed: calcium, potassium and sodium content, total soluble solids, pH, titratable acidity, color, physical stability	[67]
Chickpea and lupin	Assessment of the impact of processing on the nutritional properties of plant-based beverages, aiming to optimize protein and mineral digestibility and bioavailability	[68]

Table 1. *Cont.*

Raw Material	Objective	Reference
Chickpea and oat	Evaluation of the effects of oat and chickpea extract concentrations on the physicochemical, bioactive, and sensory properties of a plant-based beverage during 28 days of refrigerated storage	[69]
Coconut	Evaluation of the physicochemical, proximate, vitamin and mineral composition of fortified drinks produced from coconut milk, cocoa powder, and sugar	[70]
Coconut, cashew and soya	Evaluation of the sensory properties and acceptability of conventional and plant-based ice cream and frozen dessert, as well as the impact of the ingredient list on consumer perception and the acceptability of these products were analyzed	[71]
Corn	Evaluation of the nutritional profile of corn milk yogurt with different starter cultures, focusing on macronutrients and changes in micronutrients and bioactive compounds during fermentation	[72]
Corn	Physicochemical, antioxidant, microstructure, textural, and organoleptic characteristics of this soft corn drink-supplemented cheese at different concentrations of up to 40% were analyzed	[73]
Corn	Evaluation of the effects of boiling and steaming on the physicochemical, functional, microbiological properties, sensory acceptance, and shelf life of purple corn milk, including the impact of sucrose during 12 days of storage at 4 °C	[74]
Hazelnut	Investigation of the effects of high-pressure homogenized hazelnut milk enrichment on the rheological, textural, physical, functional, and sensory properties of ice cream	[75]
Hazelnut	Evaluation of the effects of hazelnut type, hydrocolloid concentration, and ultrasound treatment on the physicochemical and sensory properties, aiming to identify the optimal formulation for producing a stable hazelnut beverage	[76]
Macadamia	Evaluation of the effect of xanthan gum and soy lecithin on the physicochemical stability, fatty acid profile, and antioxidant capacity with and without thermal treatment, and physicochemical changes during storage and sensorial acceptability	[77]
Oat	Evaluation of the effects of different treatments (hot water, acid, alkali, α-amylase and germination, isolated or combined) of oat paste on the nutritional, functional and sensory properties of oat milk	[78]
Pea, bean and sunflower seeds	Development of a beverage based on pea, bean, and sunflower seeds with natural bioactive stabilizers (guar gum, pectin, and locust bean gum)	[79]
Pea, chickpea and lupin	Development of legume-based beverages by identifying optimal processing methods to achieve high protein content and a mild legume flavor, while minimizing residues and enhancing sensory quality and beverage stability	[32]
Peanut, oat, and chickpea	Optimization of a blended plant-based beverage, with evaluation of its nutritional, functional, microbiological, and sensory properties	[80]
Pistachio	Development of a pistachio-based plant beverage with high protein, unsaturated fatty acids, and phenolic content, evaluating flavor, sensory properties, antioxidant activity, and the fate of phenolic compounds after in vitro digestion	[81]
Pistachio	Development and characterization of a fermented beverage produced via colloidal milling using selected lactic acid bacteria	[82]

Table 1. *Cont.*

Raw Material	Objective	Reference
Pistachio	Models were used to assess the fermentative behavior of the bacteria in the beverage, while an electronic nose (E-nose) was employed to differentiate the fermented samples based on their aroma profiles	[83]
Pistachio, lupin and almond	Development of a clean-label plant-based milk suitable for future fermented products, utilizing by-products for sustainable production	[84]
Quinoa	Evaluation of the potential of quinoa for producing gluten-free beverages for the development of a beverage addressing nutritional composition, sugar content, glycemic index, technological properties, and sensory acceptance, in comparison with a commercial quinoa-based beverage	[85]
Quinoa	Evaluation of the effects of different bioprocessing methods (soaking, germination, malting, and dehulling) on nutritional, functional, and sensory properties of a saponin-free quinoa-based beverage	[86]
Quinoa	Quinoa was fermented using individual strains and combinations of lactic acid bacteria to assess the effects of fermentation on nutritional composition, functional components, and digestibility. Fermented quinoa milk was then produced with the selected strains, and its physicochemical properties and flavor profile were evaluated	[87]
Rice	Development of a ready-to-serve, value-added rice milk product using two rice varieties (Oryza sativa), incorporating locally available spices: clove (*Syzygium aromaticum*), ginger (*Zingiber officinale*) and garlic (*Allium sativum*)	[88]
Rice	Characterization of the composition and nutritional value, evaluation of physicochemical parameters (measurement of soluble solids, pH, osmolality, foaming properties and color parameters) and sensory parameters, and evaluation of the total polyphenol content and antioxidant properties of 10 selected rice beverages available on the EU market	[89]
Sesame	Evaluation of the chemical, physical, microbiological, and sensory properties of a novel kefir beverage prepared with two types of sesame milk: permeate and water-based beverages	[90]
Sesame	Evaluation of different pre-treatments of sesame seeds (soaking in water, boiling, pressure cooking, steaming, and combinations of these methods) and thermal treatments of sesame milk (pasteurization and sterilization) with the aim of improving the yield, dispersion stability, and sensory acceptance of the product	[91]
Sesame and pumpkin	Development of a plant-based beverage from sesame and pumpkin seeds, with evaluation of sensory and nutritional properties through hedonic testing and proximate analysis, alongside a cost assessment of the beverage was carried out	[92]
Soy	Physiological, antioxidant, isoflavone, rheological, and organoleptic properties were evaluated	[93]
Soy	Physicochemical and nutritional evaluation of soymilk and a comparative study of their effect on blood gluco-lipid profile in both animal models and Type 2 diabetic patient volunteers	[94]
Soy, rice and oat	Chemical and biological safety were investigated	[95]
Sunflower	Develop a novel co-culture fermentation process using *Propionibacterium freudenreichii* and *Bacillus amyloliquefaciens* for sunflower seed-based beverages, with the aim of enhancing vitamin B_{12} production	[96]

Table 1. *Cont.*

Raw Material	Objective	Reference
Tigernut	Development of ice cream from tigernut-based beverages and comprehensive characterization of the samples, and chemical and physical composition, total phenolic and antioxidant content, cytotoxic activity, sensory attributes, and microstructure were performed and analyzed	[97]
Tigernut	Characterization of commercial tigernut ''milks" and analysis between products with and without Protected Designation of Origin (PDO), focusing on volatile compound profiles, descriptive sensory attributes, and consumer satisfaction were performed	[98]
Tigernut	The effects of replacing cow's milk with tigernut "milk" on the physicochemical, rheological, and sensory properties of ice cream were evaluated	[99]

4. Processing Technologies and Regulatory Aspects of Plant-Based Beverages

4.1. Conventional Processing vs. Emerging Technologies

As a relatively recent sector, the plant-based beverages market requires improvements in production processes to ensure its continued growth and development [100]. Despite the continued expansion of this market and the increasing consumption of these products relative to traditional dairy, several technical challenges remain to be addressed in terms of processing, safety and quality, especially those in which one does not use intensive thermal treatments and those that are more eco-friendly.

Although Ultra High Temperature (UHT) treatment is a widely used conservation tool and essential for ensuring food safety by eliminating harmful microorganisms in any liquid or predominantly liquid food matrix, protein denaturation is a well-known side effect of that. Denaturation may alter protein functionality, particularly their capacity for coagulation, thickening, and emulsification [101]. The key challenge lies in minimizing the negative impact of denaturation, particularly in products that rely heavily on the functional properties of proteins [102]. Even in UHT processing conditions, plant-based beverages are still susceptible to some microbiological contamination such as from *Bacillus cereus* and other pathogens, with some other risks amplified by insufficient processing and handling conditions [103].

Emerging technologies have the potential to provide effective solutions to these challenges. Several thermal methods such as ohmic heating (OH), microwave, dielectric, and radio frequency heating, and non-thermal approaches such as high-pressure processing (HPP), ultrasound (US), moderate electric field (MEF) and pulsed electric field (PEF) are being employed for the preservation of plant-based beverages [104], fruit juices [105], and fermented drinks [106].

To cite some examples, in the scenario of OH, MEF, and PEF, they use electrical energy for short periods (μs–min) on food disposed between electrodes. The key difference is the temperature: while OH is a thermal process where food heats rapidly as an electrical resistor, MEF and PEF are non-thermal methods [106]. These last two technologies may potentially enhance the phytochemical content of plant-based ingredients to develop clean-label minimally processed beverages with health benefits, even with the need for more in-depth study in order to understand underlying mechanisms and the processing parameters for different raw materials [104]. In research by Sampedro et al. [107], for instance, PEF treatment achieved the same degree of microbial and enzyme inactivation as the thermal treatment in an orange juice–milk-based beverage.

High-pressure processing (HPP), in turn, is one of the innovative technologies and brings strong positive benefits, utilizing pressure rather than heat to ensure microbial safety and helping in the preservation of protein functionality and the improvement of sensory characteristics of plant-based milk-like products [102]. HPP application in plant-based beverages enables effective microbial inactivation and shelf-life extension while maintaining better preservation of color and overall quality compared to thermal treatments [108]. For example, a treatment at 450 MPa for 5 min was sufficient to inactivate the main target microorganisms over nine weeks of storage, with performance comparable to thermal treatment [109]. At the same time, HPP also preserves foods' natural flavors and nutritional integrity, reinforcing its role as a promising non-thermal processing technology [110].

On the other hand, ultrasound technology (US) is an extraction technique that often yields positive outcomes, such as enhancing the bioavailability of certain compounds, producing bubbles that undergo collisions [111], improving the efficiency of subsequent treatments. It is a way to disrupt the cellular structure of matrices, bringing considerable effects on the physical, biochemical, and mechanical properties of food products [112]. A combination of ultrasound-assisted extraction (US-AE) with thermosonication, for example, plays a crucial role in plant-based beverages by not only improving the recovery of bioactive compounds from complex plant matrices but also helping to preserve their quality, stability, and biological functionality throughout processing [113]. Two other relevant examples in this context are reported by Salve et al. [114], who verified lower pH values, color changes, microbial reduction, and improved rheological behavior in treated samples, characterized by smaller particle size and better results of sedimentation in peanut "milk"; and Maghsoudlou et al. [115], who also reported color changes, reduced particle size, and improved particle stability, along with complete microbial inhibition in almond "milk".

4.2. Highlights of Regulatory Framework

Given the urgency of developing novel milk alternatives, it is also essential to establish regulatory frameworks that ensure safety and quality in the production of these products and also in their correct nomenclature. It is evident that regulations for plant-based, non-dairy beverages vary worldwide. One example of a failure in this regulatory context is the lack of specific guidance for the nutritional profile or labeling of plant-based beverages by the Codex Alimentarius Commission [116].

In the United States of America (USA), the FDA (Food and Drug Administration) requires compliance with federal, state, and local rules regarding production, labeling, packaging, and distribution. Allergen declarations are mandatory, shelf-life limits are defined (six months for ambient temperature products, and three months for refrigerated ones), and the Food Safety and Inspection Service (FSIS) can carry out tests to ensure microbiological and analytical safety [117]. Products labeled as 'milk' are required to meet specific standards, including a nutritional profile comparable to conventional milk. Since non-dairy beverages do not fulfill these criteria, plant-based milk alternatives (PBMAs) cannot be marketed or sold as 'milk' under the United States Food, Drug, and Cosmetic (FD&C) Act [118]. In January 2025, the FDA released a 'Guidance for Industry' related to the labeling of plant-based alternatives to animal-derived products'. However, the guidance does not specifically address the naming and labeling of PBMAs, leaving important gaps for standardization and regulatory interpretation [119]. It is a more flexible body focused on providing information to consumers, not on restricting names.

Related to Europe, Regulation (EU) 1308/2013 defines 'milk products' as those derived exclusively from milk (mammalian gland secretions)—as mentioned before—and reserves dairy terms such as milk, butter, and yogurt exclusively for these products, thereby establishing clear legal boundaries within the European market [120]. In other words, dairy

alternative products cannot be referred to with dairy-associated names, such as "oat milk", "cashew milk", "sesame milk", with some exceptions, for example, "peanut butter" and "coconut milk". Inside Europe, some definitions within countries were delimited by a Commission Decision 2010/791/EU, such as the use of the expression "lait d'amande" in French, whereas the same expression in English, "almond milk," is not indicated by regulations [121]. It is certain that food labeling plays a key role in shaping consumers' perceptions of the nutritional benefits of products. Therefore, the use of nutrition and health claims is also subject to specific regulations. Nutrition and health claims are regulated under Regulation (EC) No 1924/2006, and voluntary vitamin/mineral fortification is governed by Regulation (EC) No 1925/2006—both directly relevant when consumers compare fortified plant-based milk and dairy alternatives (PBMDAs) with dairy products [122–124].

In terms of regulation from Brazil, the country does not yet have specific regulations exclusively for plant-based products. However, these products are still subject to oversight under existing general food regulations by national authorities, such as ANVISA (National Health Surveillance Agency) and MAPA (Ministry of Agriculture, Livestock, and Supply). While regulators argue that the current framework is sufficient, efforts are ongoing to identify regulatory gaps and challenges. In practice, plant-based products are understood as processed foods of plant origin designed to mimic the sensory and functional characteristics of animal-derived products [125]. There is only a specific section of RDC 726/2022 in effect regarding the naming and marketing of products derived from edible fruits, vegetables, or mushrooms, which stipulates that such products cannot be marketed or sold under the designation "soy milk" [126]. These plant-based products are still subject to oversight under existing general food regulations by national authorities, including MAPA (Ministry of Agriculture, Livestock, and Supply) in addition to ANVISA itself. Concerning the market, the prevalence of incorrect product designations highlights a clear need for regulatory enforcement in Brazil, as demonstrated by Pereira et al. [127], who also identified that, among 148 dairy analogs in Brazilian supermarkets, 33 products contained the term "milk" in their denomination, including "soy milk" (0.7%), "plant-based milk" (2.0%), and "coconut milk" (19.6%). In practical terms, while regulators argue that the current framework is sufficient, efforts are ongoing to identify regulatory gaps and challenges.

The regulatory framework for plant-based beverages remains fragmented worldwide, with no specific nutrient labeling guidelines from major authorities such as the FDA, EFSA (European Food Safety Authority), or even the prestigious international standards of Codex Alimentarius. Similar gaps are observed in Africa [128] and in countries in Asia and Oceania, where regulations are still developing or rely on general food laws. Strengthening and harmonizing regulatory approaches is essential to improve transparency, support innovation, and ensure consumer trust, as is also evident in the case of plant proteins [129]. Ultimately, more comprehensive regulations will benefit society by promoting informed choices and more sustainable food systems.

5. Nutritional Profile and Fortification Strategies

The increasing consumption of PBBs has intensified the discussion regarding their nutritional adequacy, particularly when these products are used as substitutes for cow's milk, which is one of the most widely consumed types of milk worldwide [130,131]. In contrast to cow's milk, which naturally provides a balanced composition of proteins, lipids, vitamins, and minerals, plant-based beverages are complex formulations whose nutritional value depends on the plant raw material, processing conditions, and formulation strategies [30,60,132,133]. In many cases, these PBBs present lower protein contents, differences in amino acid profiles, and reduced levels of bioavailable micronutrients when compared to cow's milk [59,131]. Consequently, fortification with vitamins, minerals, and other func-

tional ingredients has a technological approach to improve the nutritional quality of these products and to ensure their nutritional adequacy [134].

The nutritional composition of plant-based beverages varies considerably according to the botanical source and formulation. Legume-based beverages, such as soy, generally present higher protein contents, whereas cereal-based beverages, including oat and rice, tend to contain higher carbohydrate levels and lower protein concentration [7,135,136]. Coconut-based beverages usually contain low protein levels and variable lipid content depending on processing and dilution conditions [137,138].

Values reported for commercially available products confirm the wide differences in nutritional composition among plant-based beverages. The nutritional compositions of cow's milk and selected commercial plant-based beverages reported in recent studies (2020–2026) are presented in Table 2. Overall, soy-based beverages generally present a nutritional composition closer to that of cow's milk, particularly regarding protein content, whereas oat-, rice-, almond-, and coconut-based beverages tend to show lower protein levels and greater variability in carbohydrate and fat composition. In addition, rice-based beverages generally exhibit higher carbohydrate contents, while coconut-based beverages tend to contain more fat.

Table 2. Average nutritional composition values of commercial cow's milk and plant-based beverages reported in recent studies (2020–2026).

Category	Geographic Market	Energy	Protein	Fat	Carbohydrate	Reference
Cow's milk	UK	50 kcal/100 mL	3.5 g/100 mL	1.8 g/100 mL	4.8 g/100 mL	[13]
Cow's milk	Melbourne/Sydney	~33 kcal/100 mL	~3.6 g/100 mL	1.4 g/100 mL	-	[139]
Soy	China	46.1 kcal/100 mL	3 g/100 mL	1.8 g/100 mL	4.2 g/100 mL	[135]
Soy	Ukraine	46.2 kcal/100 mL	5.2 g/100 mL	1.8 g/100 mL	2.53 g/100 mL	[140]
Oat	Italy	61 kcal/100 mL	<0.5 g/100 mL	2 g/100 mL	10 g/100 mL	[141]
Oat	Copenhagen/Denmark	36 kcal/100 mL	1 g/100 mL	0.5 g/100 mL	6.5 g/100 mL	[142]
Almond	Italy	38 kcal/100 mL	0.8 g/100 mL	2.3 g/100 mL	3 g/100 mL	[143]
Almond	China	38.24 kcal/100 mL	1 g/100 mL	2.1 g/100 mL	4.9 g/100 mL	[135]
Rice	Spanish	55.5 kcal/100 mL	0.36 g/100 mL	1 g/100 mL	11.2 g/100 mL	[7]
Rice	EU	47 kcal/100 mL	0.1 g/100 mL	1 g/100 mL	9.5 g/100 mL	[89]
Coconut	UK	33.67 kcal/100 mL	0.28 g/100 mL	1.88 g/100 mL	3.70 g/100 mL	[144]
Coconut	Melbourne and Sydney	~33 kcal/100 mL	~0.2 g/100 mL	2.2 g/100 mL	-	[139]
Pea	China	32.74 kcal/100 mL	1 g/100 mL	1.6 g/100 mL	3.5 g/100 mL	[135]
Pea	UK	25 kcal/100 mL	2 g/100 mL	1.96 g/100 mL	0.42 g/100 mL	[13]

Plant-based beverages (PBBs) may contain bioactive compounds naturally present in the plant raw materials used for their production, which can affect both their nutritional value and functional properties [33,46,144,145]. Oat-based products are commonly characterized by the presence of β-glucans, whereas soy beverages provide isoflavones and phytosterols. Tocopherols are typically associated with almond beverages, while rice-based formulations may contain phytosterols such as β-sitosterol and γ-oryzanol [33]. On the other hand, the presence of antinutritional compounds should also be considered in plant-based beverages; for example, oat- and sesame-based beverages may contain phytates and oxalates [46].

Due to variability in composition and their natural low concentrations, to compensate nutritional limitations, plant-based beverages are often supplemented with selected vitamins, minerals, and protein ingredients during the formulation step [46,146]. The replacement of cow's milk with plant-based, particularly cereal-based, beverages may increase the risk of nutritional inadequacy, especially when these products are not properly fortified [6]. Commonly involving the addition of vitamins (e.g., A, B-complex, D, and E), minerals such as calcium, other functional ingredients, and compounds such as omega-3 fatty acids may also be incorporated to enhance the nutritional profile of the final prod-

uct [146,147]. A qualitative comparison of cow's milk and representative PBBs as vitamin sources is illustrated in Figure 3.

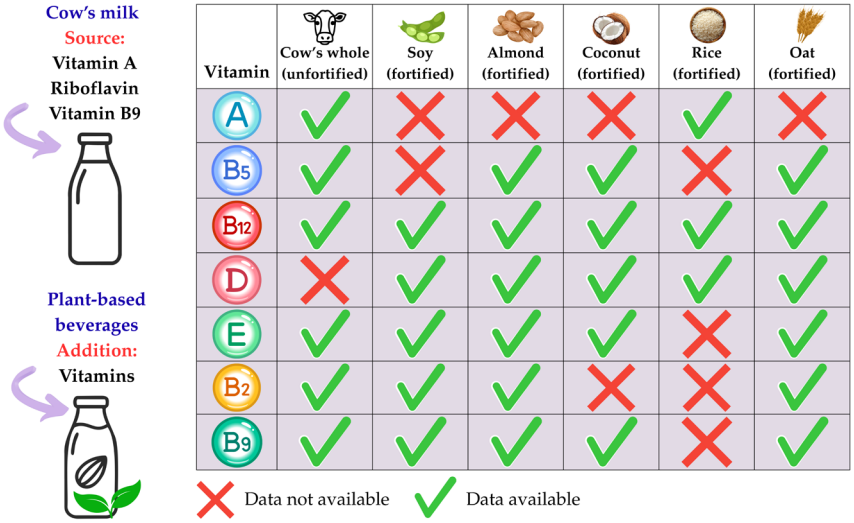


Figure 3. Schematic comparison of cow's milk and plant-based beverages as sources of vitamins. Developed by the authors based on information reported in [26].

The contents of vitamin B_2 and vitamin B_{12} vary considerably among plant-based beverages depending on raw material and fortification practices. The reported levels of these vitamins in cow's milk and selected plant-based beverages are summarized in Table 3.

Table 3. Examples of vitamins B_2 and B_{12} contents in cow's milk and plant-based beverages.

Vitamin	Cow's Milk	Coconut	Grains	Legumes	Nuts/Seed	Mixed	Reference
B_2 (mg/100 mL)	0.21	0	0.001	0.04	0.0024	0.007	[139]
B_2 (mg/100 mL)	0.24	0.50	0.21	0.21	0.21	0.21	[144]
B_{12} (µg/100 mL)	0.6	0	0	0	0	0.4	[139]
B_{12} (µg/100 mL)	0.79	0.39	0.38	0.44	0.38	0.38	[144]

Fortification strategies in PBBs must consider issues related to physical stability and micronutrient bioavailability, which are influenced by the plant matrix and the presence of added compounds [33,148,149]. Interactions among proteins, lipids, minerals, and antinutritional compounds may affect colloidal stability and nutrient dispersion, making the assessment of gastrointestinal bioavailability an important aspect in the development of fortified plant-based beverages [60,147,150,151]. For example, Zhou et al. [151] investigated a formulation strategy based on the simultaneous fortification of almond ''milk" with vitamin D and calcium using controlled delivery systems. Vitamin D was incorporated through an oil-in-water nanoemulsion designed to enhance dispersion and stability of this lipophilic micronutrient, while calcium was added in different chemical forms ($CaCl_2$ or $CaCO_3$) and at different concentrations to evaluate their effects on physicochemical properties and nutrient bioaccessibility. The results showed that the type and levels of calcium strongly influenced colloidal stability and nutrient availability, since high concentrations of calcium ions promoted particle aggregation and reduced vitamin D bioaccessibility due to the formation of insoluble calcium soaps during digestion.

6. Physicochemical, Technological and Sensory Challenges

Plant-based beverages (PBBs) present physicochemical, technological and sensory challenges in comparison to cow's milk and complicate the development of stable and

acceptable products [6,46,47,152,153]. Dairy milk is a naturally stable colloidal system composed of fat globules, casein micelles, and soluble protein [134], while PBBs are typically complex dispersions obtained from plant tissues containing insoluble particles, protein, starch, lipids and dietary fiber [50,133,134]. Consequently, PBBs systems may exhibit physical instability, phase separation, undesirable texture, and flavor defects [33,46,154].

One of the main technological limitations of PBBs is the susceptibility to physical instability during storage, which is related to the complex colloidal nature of these systems. Plant-based beverages are typically suspensions or emulsions composed of particles with different sizes, densities, and compositions, including proteins, lipids, carbohydrates, and fragments of plant tissues [6,155–157]. Due to this structural complexity, these products are prone to sedimentation, creaming, and phase separation over time [6,155]. Insoluble components such as starch granules and protein aggregates tend to settle under gravity, leading to the formation of sediment and a non-uniform appearance [6,46,158–160].

In addition, the sensory quality of these beverages is largely influenced by their colloidal stability and by their physicochemical and rheological properties, particularly viscosity and the interactions between proteins, polysaccharides, and lipids [161,162]. Variations in these parameters affect texture, mouthfeel, and visual appearance, which are critical attributes for consumer acceptance [161–163].

To overcome these limitations, formulation strategies are commonly applied to improve dispersion stability. Thickening agents and stabilizing additives, especially hydrocolloids such as carrageenan, xanthan gum, guar gum, pectin, alginates, and modified starch, are frequently incorporated to increase viscosity, reduce gravitational separation phenomena such as the creaming of oil bodies or fat droplets, and the sedimentation of proteins or insoluble plant particles [134,164]. For example, Sen and Okur [76] evaluated the effect of hydrocolloid concentration and ultrasound processing on hazelnut-based ‘‘milk” and reported that both formulation and processing conditions strongly influenced particle size distribution, physicochemical properties, and sensory characteristics, highlighting that dispersion stability is one of the main challenges in the production of plant-based beverages. Gama et al. [161] evaluated the effect of different hydrocolloid combinations on the rheological and stability properties of a peanut-based beverage and observed that formulations containing xanthan gum exhibited higher viscosity and more pronounced shear-thinning behavior, which contributed to improved suspension stability.

Even though the inclusion of these hydrocolloids is important to prevent phase separation and promote homogenization in PBBs, they may frighten label-conscious consumers due to longer ingredient lists, which are often perceived negatively and associated with “E-numbers”—the term for food additives in Europe according to Regulation EU 1333/2008 with amendments [165].

This reflects the clean-label trend, which is related to consumers’ perception of individual ingredients on food labels, focusing on the quantity and quality of the products [166]. A clean-label product is defined by the Institute of Food Technologists as one made with a minimal number of ingredients that consumers can understand and perceive as healthy [167]. Although not required by food regulations, clean-label foods reflect a growing emphasis on health consciousness and environmental responsibility. Due to such challenges, the scientific research has been driven towards innovation in the development of clean-label alternatives, focusing on the replacement of synthetic additives with natural ingredients, as exemplified by the use of algae for this purpose. Algae, for instance, not only contribute with biochemical properties but also enhance food rheology, as their macronutrient composition influences microstructure and gel formation, reducing the need for additional thickeners and stabilizers [168].

In addition to physical instability, PBBs often present sensory limitations that may reduce consumer acceptance. Many plant raw materials contain compounds responsible for characteristic off-flavors, such as the beany taste commonly associated with soy beverages or the earthy and bitter notes found in pea and cereal-based products [169,170]. These undesirable flavors may originate from lipid oxidation, enzymatic activity, or the presence of phenolic compounds and other secondary metabolites [169]. For example, lipoxygenase activity can promote the formation of volatile aldehydes responsible for undesirable aromas [171]. In addition, soy beverages are also susceptible to off-flavor formation through Maillard reactions, since their naturally high content of free amino acids and reducing sugars favor the development of bitter, burnt, or overly intense flavors when processing conditions are not properly controlled [172].

Different technological approaches have been proposed to reduce these sensory defects, including thermal processing, enzymatic treatments, fermentation, and flavor masking, but these strategies may also alter the nutritional and functional properties of the beverages [46,100,154,173]. For instance, the use of selected microbial cultures has been investigated as a way to improve the organoleptic quality of fermented soy milk, promoting changes in volatile compounds and reducing the perception of undesirable flavors [161].

7. Sustainability and Environmental Assessment

Food production, especially of animal origin, represents one of the major contributors to global climate change, accounting for approximately 20–30% of overall environmental impacts [174]. The livestock sector is a key driver of greenhouse gas emissions (accounting for approximately 14.5%), and is also associated with intensive water consumption, biodiversity loss, and extensive use of agricultural land [175]. As a result, replacing animal-based foods with plant-based alternatives has been proposed as a strategy to mitigate these environmental impacts.

According to FAO [176], the global greenhouse gas (GHG) emission intensity in 2020 was approximately 1 kg CO_2-eq per kg cow's milk. Among cereal crops, rice exhibited a comparable emission intensity, also around 1 kg CO_2-eq per kg of product, whereas other cereals—considering barley, maize, millet, oat, rye, sorghum, and wheat—showed substantially lower emission intensities, with 0.2 kg CO_2-eq per kg.

Life cycle assessment (LCA) is a recognized methodological framework, standardized by ISO norms, widely applied to assess the environmental impacts of livestock production systems throughout their entire life cycle. This method enables the quantification of various impact categories, including greenhouse gas (GHG) emissions, water and land use, biodiversity impacts, eutrophication, and toxicity, among others [177].

Considering the entire production chain, cow's milk is associated with higher environmental impacts than plant-based beverages (PBBs). The production of one liter of cow's milk results in approximately twice the impact of a soy-based beverage, whereas comparisons with other plant-based beverages show differences of approximately three- to five-fold lower impacts as demonstrated in Table 4.

Table 4. Comparison of cradle-to-gate LCA studies for cow's milk and plant-based beverages.

Product	kg CO_2-eq/L	Reference
Cow milk	0.99–1.08	[10]
Soy-based beverage	0.51–0.52	
Oat-based beverage	0.38	[178]
Almond-based beverage	0.26	
Coconut-based beverage	0.29	
Ripple pea-based beverage	0.29	

The production chain of soy-based beverages is relatively simpler than that of cow's milk, as soybeans are transported directly from harvest to industrial processing. A study by Coluccia et al. [10] reported that in soy-based beverage manufacturing, most greenhouse gas emissions occur during the industrial stage, particularly in processing and packaging operations, which account for approximately 79.2% of the total carbon footprint. The same study also demonstrated that, for cow's milk, more than 80% of total emissions are associated with upstream stages, particularly livestock farming, which alone accounts for over 60% of the total carbon footprint. Additionally, Costa et al. [179] evaluated the replacement of cow's milk with soy-based beverages using a consequential life cycle assessment approach and concluded that this substitution alone does not significantly reduce GHG emissions unless it is accompanied by a reduction in beef consumption. Nevertheless, land sparing associated with this substitution may contribute to emission mitigation when combined with reforestation strategies.

Overall, the available literature indicates that dairy beverages are generally associated with higher environmental impacts than plant-based beverages. However, when impact categories are evaluated individually, plant-based beverages do not constantly show lower values than cow's milk. For example, the environmental impacts of major plant-based beverages, including oat-, soy-, and almond-based beverages, were analyzed and compared with those of conventional and organic cow's milk using LCAs across 12 impact categories, showed that oat- and soy-based beverages generally exhibited the lowest environmental impacts [175]. By contrast, in the freshwater exotoxicity category, soy-based beverages exhibited higher values (4.45×10^{-3} kg 1.4-DCB—dichlorbenzene-equivalent) compared to conventional milk (2.11×10^{-3} kg 1.4-DCB). A similar trend was observed for ecosystem damage potential, with values of 3.48 points for soy-based beverages and 1.76 points for conventional milk [175].

The LCA has increasingly incorporated environmental impacts and nutritional value by adopting nutritional functional units (nFUs) based on nutrient density indices. In this context, Kovanen et al. [180] developed a nutritional index to be used as an nFU, applying LCA data to compare the environmental impacts of milk and plant-based beverages. Their findings demonstrated that the selection of the functional unit significantly affects LCA results and the comparative interpretation of products, particularly when conventional volume-based functional units are employed.

8. Market Trends and Commercial Products

Summarily, the consumption of plant-based beverages has increased in recent years, driven by environmental concerns, animal welfare considerations, and health-related factors. These products are commonly associated with lower environmental impacts and are considered suitable alternatives for individuals with lactose intolerance or cow's milk allergy. Furthermore, plant-based beverages are often perceived by consumers as more sustainable and easier to digest. However, aspects such as price and sensory attributes remain important determinants of consumer acceptance in the market [174].

Consumer preferences for plant-based milk and dairy alternatives (PBMDAs) are also influenced by sociodemographic factors, with greater adoption observed among younger consumers, women, and individuals with higher educational levels. Sensory attributes, including flavor, texture, and mouthfeel, play a crucial role in consumer acceptance and repurchase intention, particularly when these products mimic the characteristics of dairy counterparts [122]. A study conducted in China in 2021 [181] investigated consumer preferences (n = 819) and willingness to pay (WTP) for plant-based products. The results indicated that product attributes such as appearance, taste, nutritional value, and perceived environmental benefits positively influence consumers' WTP. Moreover, WTP varies across

demographic segments, being higher among women, younger consumers, individuals with higher income and education levels, urban residents, and those with greater environmental awareness. Specific groups, such as lactose-intolerant individuals, vegetarians, and those with particular dietary requirements, tended to demonstrate a higher WTP.

According to Future Market Insights, the market for plant-based milk alternatives is expected to grow significantly, reaching USD 23.8 billion by 2026 and expanding at a compound annual growth rate (CAGR) of 9.2% through 2036, with projections indicating a market value of USD 57.2 billion by the end of the period. The Asia-Pacific region dominates the PBB market in terms of volume, largely driven by traditional plant-based dietary habits and the high prevalence of lactose intolerance. Countries such as India and China are projected to experience the highest growth rates, with a CAGR of 12.1% and 11.8%, respectively, between 2026 and 2036. North America is characterized by strong innovation and the development of functional beverages, whereas European markets, including Germany (7.4%) and the United Kingdom (7.1%), are expected to show more moderate growth. In the United States, the projected CAGR is 8.2% [182].

Data provided by Fortune Business Insights indicates even more promising prospects for the global plant-based milk alternatives market. According to these estimates, the sector was valued at USD 36.76 billion in 2025 and is projected to reach USD 41.75 billion in 2026, with further growth expected to attain USD 117.64 billion by 2034, corresponding to a CAGR of 13.83% over the period. The regional distribution of the global plant-based milk alternatives market, highlighting 2025 values, market share percentages, and projections for 2026, is shown in Table 5. These data underscore the strong concentration of the market in the Asia-Pacific region, as well as consistent growth in regions such as North America and Europe [183].

Table 5. Regional distribution of the global plant-based milk alternatives market, including market value (USD billions), market share (%), and projections for 2026. Based on information reported in [183].

Region	2025 (USD Billions)	Share (%)	2026 (USD Billions)
Asia-Pacific	19.42	52.83	22.14
North America	9.08	24.70	10.26
Europe	6.83	18.58	7.74
Latin America	1.38	3.74	1.55
Middle East and Africa	0.06	0.15	0.06

A consumer study carried out in 2021 [184], involving 7590 individuals aged over 18 across 10 European countries, showed that 37% of respondents identified themselves as flexitarians, vegetarians, or vegans. Regarding PBB consumption, 12% of participants reported consuming these products 1–3 times per month, 11% 1–3 times per week, 7% 4–6 times per week, and 10% 1–2 times per day. A similar trend was observed in data reported by Statista [185], showing that in 2023, among flexitarian consumers in selected European countries, 16% consumed PBBs 1–3 times per month, 15% 1–3 times per week, 9% 4–6 times per week, and 12% 1–2 times per day.

In recent years, companies in the food sector have expanded their product portfolios by investing in PBBs as a diversification strategy. Among them, Oatly has emerged as a key player in the PBB market, particularly with oat-based products, including barista-style, light, and protein-enriched formulations. These products have shown strong acceptance, especially in coffee applications, due to their favorable flavor and textural properties. Danone, through brands such as Alpro and Silk, has developed a diversified portfolio of PBBs, encompassing oat-, soy-, and almond-based products, including fortified formulations (e.g., calcium and vitamins) and reduced-sugar options, thereby strengthening its global market presence. Furthermore, Blue Diamond, with its Almond Breeze line, focused on

almond-based beverages, offers a range of products such as original, unsweetened, and barista-style formulations, and is widely recognized as a leading brand in this segment; and Califia Farms has focused on innovation in PBBs, offering almond-, oat-, and blended formulations, including products with higher protein content and a premium positioning, emphasizing quality and differentiated formulations. In Asia, Vitasoy has established a strong presence with soy-based and other PBBs, prioritizing nutritional value and tailoring products to local market preferences. Finally, small brands such as Elmhurst 1925, along with emerging startups, have increasingly focused on developing simpler and more natural formulations, often characterized by minimal ingredient lists, higher protein content, and innovative product concepts, targeting specific market niches [34].

9. Challenges and Future Perspectives

The development of PBBs is associated with multiple challenges, including physicochemical instability, the need for nutritional fortification, undesirable sensory attributes, and technological limitations related to processing. Furthermore, despite increasing market demand, consumer acceptance is still constrained by factors such as the relatively high cost of these products [15]. In this context, sensory attributes, particularly texture and flavor are key determinants of consumer acceptance and purchasing decisions. The presence of compounds such as phenolics and flavonoids may contribute to bitterness in PBBs, while prolonged storage can negatively affect sensory quality due to lipid degradation and the formation of undesirable compounds [34].

Food manufacturers face the challenge of balancing sensory quality and nutritional value in PBBs. Products with improved palatability often contain higher levels of sugars and additives, which may reduce their attractiveness to health-conscious consumers, whereas nutritionally optimized formulations tend to present less favorable sensory characteristics. Therefore, achieving an appropriate balance between these attributes is critical for the development of competitive products [7].

According to the study by Clegg et al. [144], a major limitation when comparing dairy products with plant-based alternatives is the difference in their nutritional composition, particularly regarding protein, vitamin B_{12}, calcium, and iodine content. The study also reported that these differences may pose potential health risks for vulnerable populations, including children, older adults, and pregnant women. Furthermore, the wide variability in composition and fortification levels among products available on the market makes it difficult for consumers to make informed choices, while the relatively higher cost of plant-based alternatives may limit their accessibility.

Life cycle assessment, although an essential tool for providing insights into more sustainable food systems, presents significant challenges related to the lack of standardized guidelines, the complexity of cross-sector interactions, and the reliance on multiple modeling assumptions, particularly in consequential LCA approaches. These limitations may lead to considerable variability in results, requiring careful interpretation and a comprehensive understanding of the economic and biophysical interconnections across agri-food supply chains [179].

In summary, nutritional fortification of plant-based alternatives is essential to reduce disparities relative to dairy products and to improve their nutritional quality. Increasing consumer awareness and education is critical to avoid the misconception that these products are inherently healthier, thereby supporting more informed and appropriate dietary choices. The development of more comprehensive LCA frameworks is needed to enable more balanced and meaningful comparisons between products. Finally, the plant-based sector presents significant potential for innovation, including the development of more nutritionally balanced formulations and the expansion of research integrating health and

sustainability, contributing to more accessible and efficient food systems and to more informed public policy decisions. The current limitations of PBBs and the main directions for future development are summarized in Figure 4.

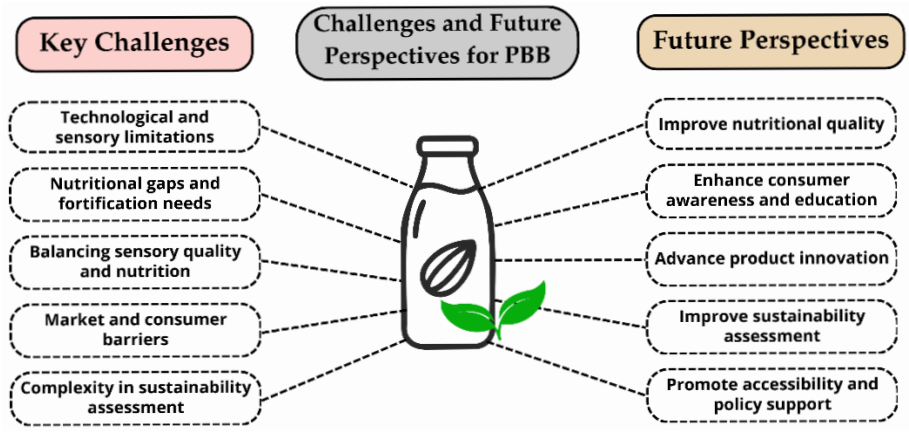


Figure 4. Main challenges and future perspectives for plant-based beverages (PBBs).

10. Conclusions

Plant-based beverages represent a rapidly expanding and highly promising category within food systems, but they cannot yet be considered fully nutritionally and technologically equivalent alternatives to cow's milk. Strategies related to formulation and/or incorporation, particularly nutritional fortification and process optimization, can partially compensate for limitations related to protein quality, micronutrient content, and physicochemical stability. In this context, PBBs may serve as viable alternatives when properly formulated and consumed within balanced diets. On the other hand, significant challenges remain, including variability in composition, sensory limitations, and constraints in current environmental assessment methodologies. The transition towards PBBs as effective dairy alternatives will depend on achieving a balance between nutritional adequacy, technological performance, consumer acceptance, and environmental sustainability.

Author Contributions: Conceptualization, F.P.d.A., W.d.S.C. and J.M.S.-S.; writing—original draft preparation, F.P.d.A., W.d.S.C. and J.M.S.-S.; writing—review and editing, A.R. and C.E.d.F.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research work was supported by: (i) National Council for Scientific and Technological Development of Brazil (CNPq) (project numbers: 312996/2022-5, 404455/2024-7, 440026/2024-5, 445932/2024-4 and 403991/2024-2); (ii) the Research Support Foundation of Alagoas (FAPEAL) (project numbers: E:60030.0000002360/2022, E:60030.0000000318/2023 and E:60030.0000001407/2025); and (iii) FCT—Fundação para a Ciência e Tecnologia, I.P. through project UID/04129/2025 (https://doi.org/10.54499/UID/04129/2025) of LEAF—Linking Landscape, Environment, Agriculture and Food.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors express their sincere gratitude to the National Council for Scientific and Technological Development of Brazil (CNPq), Research Support Foundation of Alagoas (FAPEAL) and FCT—Fundação para a Ciência e Tecnologia for their financial support through the scholarships awarded. The authors used ChatGPT (GPT-5.5, OpenAI, San Francisco, CA, USA) for basic editing to improve English language usage and readability. (The authors reviewed and edited the output and take full responsibility for the content of this publication).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Park, Y.W.; Haenlein, G.F.W. *Milk and Dairy Products in Human Nutrition: Production, Composition and Health*; Wiley: Hoboken, NJ, USA, 2013; ISBN 978-0-470-67418-5.
2. Anjos, O.; Pires, P.C.P.; Gonçalves, J.; Estevinho, L.M.; Mendonça, A.G.; Guiné, R.P.F. Plant-Based Beverages: Consumption Habits, Perception and Knowledge on a Sample of Portuguese Citizens. *Foods* **2024**, *13*, 3235. [CrossRef]
3. Ferrari, L.; Panaite, S.-A.; Bertazzo, A.; Visioli, F. Animal- and Plant-Based Protein Sources: A Scoping Review of Human Health Outcomes and Environmental Impact. *Nutrients* **2022**, *14*, 5115. [CrossRef]
4. Popova, A.; Mihaylova, D.; Lante, A. Insights and Perspectives on Plant-Based Beverages. *Plants* **2023**, *12*, 3345. [CrossRef] [PubMed]
5. Mäkinen, O.E.; Wanhalinna, V.; Zannini, E.; Arendt, E.K. Foods for Special Dietary Needs: Non-Dairy Plant-Based Milk Substitutes and Fermented Dairy-Type Products. *Crit. Rev. Food Sci. Nutr.* **2016**, *56*, 339–349. [CrossRef]
6. Sethi, S.; Tyagi, S.K.; Anurag, R.K. Plant-Based Milk Alternatives an Emerging Segment of Functional Beverages: A Review. *J. Food Sci. Technol.* **2016**, *53*, 3408–3423. [CrossRef]
7. Pérez-Rodríguez, M.L.; Serrano-Carretero, A.; García-Herrera, P.; Cámara-Hurtado, M.; Sánchez-Mata, M.C. Plant-Based Beverages as Milk Alternatives? Nutritional and Functional Approach through Food Labelling. *Food Res. Int.* **2023**, *173*, 113244. [CrossRef] [PubMed]
8. Pointke, M.; Albrecht, E.H.; Geburt, K.; Gerken, M.; Traulsen, I.; Pawelzik, E. A Comparative Analysis of Plant-Based Milk Alternatives Part 1: Composition, Sensory, and Nutritional Value. *Sustainability* **2022**, *14*, 7996. [CrossRef]
9. Rebellato, A.P.; Fioravanti, M.I.A.; Milani, R.F.; Morgano, M.A. Composition and Bioaccessibility of Inorganic Elements in Plant-Based Yogurts. *J. Food Compos. Anal.* **2023**, *123*, 105639. [CrossRef]
10. Coluccia, B.; Agnusdei, G.P.; De Leo, F.; Vecchio, Y.; La Fata, C.M.; Miglietta, P.P. Assessing the Carbon Footprint across the Supply Chain: Cow Milk vs Soy Drink. *Sci. Total Environ.* **2022**, *806*, 151200. [CrossRef] [PubMed]
11. Luo, H.; Bao, Y.; Zhu, P. Enhancing the Functionality of Plant-Based Yogurt: Integration of Lycopene through Dual-Stage Fermentation of Soymilk. *Food Chem.* **2024**, *434*, 137511. [CrossRef]
12. Vashisht, P.; Sharma, A.; Awasti, N.; Wason, S.; Singh, L.; Sharma, S.; Charles, A.P.R.; Sharma, S.; Gill, A.; Khattra, A.K. Comparative Review of Nutri-Functional and Sensorial Properties, Health Benefits and Environmental Impact of Dairy (Bovine Milk) and Plant-Based Milk (Soy, Almond, and Oat Milk). *Food Humanit.* **2024**, *2*, 100301. [CrossRef]
13. Nowson, G.K.; Fallaize, R.; Earl, K.E. Exploring the Nutritional Profile and Cost of Plant-Based Milk Alternatives Compared with Dairy Milk in the UK with Consideration of Environmental Impact Data. *Curr. Dev. Nutr.* **2025**, *9*, 107436. [CrossRef]
14. Khanpit, V.; Viswanathan, S.; Hinrichsen, O. Environmental Impact of Animal Milk vs Plant-Based Milk: Critical Review. *J. Clean. Prod.* **2024**, *449*, 141703. [CrossRef]
15. Maree, E.; Blignaut, J.N.; Du Toit, C.J.L.; Meissner, H.H.; Ederer, P. Review: The Need for Holistic, Sector-Tailored Sustainability Assessments for Milk− and Plant-Based Beverages. *Animal* **2025**, *19*, 101348. [CrossRef]
16. Evershed, R.; Payne, S.; Sherratt, A.; Copley, M.S.; Coolidge, J.; Urem-Kotsu, D.; Kotsakis, K.; Özdoğan, M.; Özdoğan, A.E.; Nieuwenhuyse, O.; et al. Earliest Date for Milk Use in the Near East and Southeastern Europe Linked to Cattle Herding. *Nature* **2008**, *455*, 528–531. [CrossRef]
17. Pereira, P.C. Milk Nutritional Composition and Its Role in Human Health. *Nutrition* **2014**, *30*, 619–627. [CrossRef] [PubMed]
18. Chen, X.; Wei, L.; Liu, Y.; Mi, Q.; Tian, Y.; Liu, B.; Sun, Z.; Ren, K.; Cui, X.; Wang, B. Ultrasound Processing Improves Flavor Quality and Functional Lipid Profile in Goat Milk via Lipid Metabolism Modulation. *J. Dairy Sci.* **2026**, *109*, 1125–1142. [CrossRef]
19. Siddiqui, S.A.; Salman, S.H.M.; Redha, A.A.; Zannou, O.; Chabi, I.B.; Oussou, K.F.; Bhowmik, S.; Nirmal, N.P.; Maqsood, S. Physicochemical and Nutritional Properties of Different Non-Bovine Milk and Dairy Products: A Review. *Int. Dairy J.* **2024**, *148*, 105790. [CrossRef]
20. Escobar-Charry, M.A.; Quintanilla-Carvajal, M.X. An Overview of Bovine Beta-Casomorphin-7 (b-BCM7) and Its Potential Impact on Microbiota Regulation and Digestive Health. *J. Funct. Foods* **2025**, *128*, 106812. [CrossRef]
21. Food and Agriculture Organization of the United Nations. *FAOSTAT Statistical Database*; FAO: Lisbon, Portugal, 2026; Available online: https://www.fao.org/faostat/en/#data/FBS (accessed on 27 March 2026).
22. Haug, A.; Høstmark, A.T.; Harstad, O.M. Bovine Milk in Human Nutrition—A Review. *Lipids Health Dis.* **2007**, *6*, 25. [CrossRef]
23. Miciński, J.; Kowalski, I.; Szarek, J.; Zwierzchowski, G. Health-Promoting Properties of Selected Milk Components. *J. Elem.* **2013**, *18*, 14. [CrossRef]
24. Moore, L.L.; Bradlee, M.L.; Gao, D.; Singer, M.R. Effects of Average Childhood Dairy Intake on Adolescent Bone Health. *J. Pediatr.* **2008**, *153*, 667–673. [CrossRef]
25. Mandrioli, M.; Boselli, E.; Fiori, F.; Rodriguez-Estrada, M.T. Vitamin D3 in High-Quality Cow Milk: An Italian Case Study. *Foods* **2020**, *9*, 548. [CrossRef]

26. Walsh, M.C.; Gunn, C. Non-Dairy Milk Substitutes: Are They of Adequate Nutritional Composition? In *Milk Dairy Foods*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 347–369. ISBN 978-0-12-815603-2.
27. Guo, W.; Liu, S.; Khan, M.Z.; Wang, J.; Chen, T.; Alugongo, G.M.; Li, S.; Cao, Z. Bovine Milk Microbiota: Key Players, Origins, and Potential Contributions to Early-Life Gut Development. *J. Adv. Res.* **2024**, *59*, 49–64. [CrossRef] [PubMed]
28. Kouvari, M.; Panagiotakos, D.B.; Chrysohoou, C.; Georgousopoulou, E.N.; Yannakoulia, M.; Tousoulis, D.; Pitsavos, C.; Skoumas, Y.; Katinioti, N.; Papadimitriou, L.; et al. Dairy Products, Surrogate Markers, and Cardiovascular Disease: A Sex-Specific Analysis from the ATTICA Prospective Study. *Nutr. Metab. Cardiovasc. Dis.* **2020**, *30*, 2194–2206. [CrossRef]
29. Hernández, H.; Nunes, M.C.; Prista, C.; Raymundo, A. Innovative and Healthier Dairy Products through the Addition of Microalgae: A Review. *Foods* **2022**, *11*, 755. [CrossRef]
30. Walther, B.; Guggisberg, D.; Badertscher, R.; Egger, L.; Portmann, R.; Dubois, S.; Haldimann, M.; Kopf-Bolanz, K.; Rhyn, P.; Zoller, O.; et al. Comparison of Nutritional Composition between Plant-Based Drinks and Cow's Milk. *Front. Nutr.* **2022**, *9*, 988707. [CrossRef]
31. Shanthakumar, P.; Klepacka, J.; Bains, A.; Chawla, P.; Dhull, S.B.; Najda, A. The Current Situation of Pea Protein and Its Application in the Food Industry. *Molecules* **2022**, *27*, 5354. [CrossRef] [PubMed]
32. Lopes, M.; Pierrepont, C.; Duarte, C.M.; Filipe, A.; Medronho, B.; Sousa, I. Legume Beverages from Chickpea and Lupin, as New Milk Alternatives. *Foods* **2020**, *9*, 1458. [CrossRef]
33. Sharma, N.; Yeasmen, N.; Dubé, L.; Orsat, V. A Review on Current Scenario and Key Challenges of Plant-Based Functional Beverages. *Food Biosci.* **2024**, *60*, 104320. [CrossRef]
34. Asif, N.; Anwar, O.; Arif, S.; Anwar, Z.; Haq, I.U.; Ercisli, S.; Mugabi, R.; Nayik, G.A. The Rise of Plant-Based Milk Alternatives: Exploring Nutritional, Health, and Sustainability Impacts. *Food Chem. X* **2026**, *34*, 103528. [CrossRef] [PubMed]
35. Wilkinson, J.M.; Chamberlain, A.T.; Rivero, M.J. The Case for Grazing Dairy Cows. *Agronomy* **2021**, *11*, 2466. [CrossRef]
36. Huang, J.; Xu, C.; Ridoutt, B.G.; Liu, J.; Zhang, H.; Chen, F.; Li, Y. Water Availability Footprint of Milk and Milk Products from Large-Scale Dairy Production Systems in Northeast China. *J. Clean. Prod.* **2014**, *79*, 91–97. [CrossRef]
37. Bačėninaitė, D.; Džermeikaitė, K.; Antanaitis, R. Global Warming and Dairy Cattle: How to Control and Reduce Methane Emission. *Animals* **2022**, *12*, 2687. [CrossRef]
38. Daryani, D.; Pegua, K.; Aryaa, S.S. Review of Plant-Based Milk Analogue: Its Preparation, Nutritional, Physicochemical, and Organoleptic Properties. *Food Sci. Biotechnol.* **2024**, *33*, 1059–1073. [CrossRef]
39. Merritt, R.J.; Fleet, S.E.; Fifi, A.; Jump, C.; Schwartz, S.; Sentongo, T.; Duro, D.; Rudolph, J.; Turner, J. North American Society for Pediatric Gastroenterology, Hepatology, and Nutrition Position Paper. *J. Pediatr. Gastroenterol. Nutr.* **2020**, *71*, 276–281. [CrossRef]
40. Escobar-Sáez, D.; Montero-Jiménez, L.; García-Herrera, P.; Sánchez-Mata, M.C. Plant-Based Drinks for Vegetarian or Vegan Toddlers: Nutritional Evaluation of Commercial Products, and Review of Health Benefits and Potential Concerns. *Food Res. Int.* **2022**, *160*, 111646. [CrossRef]
41. Aparicio-García, N.; Martínez-Villaluenga, C.; Frias, J.; Peñas, E. Changes in Protein Profile, Bioactive Potential and Enzymatic Activities of Gluten-Free Flours Obtained from Hulled and Dehulled Oat Varieties as Affected by Germination Conditions. *LWT* **2020**, *134*, 109955. [CrossRef]
42. Jung, H.; Chen, C.-Y.O.; Blumberg, J.B.; Kwak, H.-K. The Effect of Almonds on Vitamin E Status and Cardiovascular Risk Factors in Korean Adults: A Randomized Clinical Trial. *Eur. J. Nutr.* **2018**, *57*, 2069–2079. [CrossRef] [PubMed]
43. Cismaru, M.; Edu, T. "Eat Less Meat": Beneficial for You and for the Environment—Integrating Theory and Practice to Shape Communications Encouraging a Decrease in Meat Consumption. *Int. Rev. Public Nonprofit Mark.* **2024**, *21*, 915–940. [CrossRef]
44. Verduci, E.; Di Profio, E.; Cerrato, L.; Nuzzi, G.; Riva, L.; Vizzari, G.; D'Auria, E.; Giannì, M.L.; Zuccotti, G.; Peroni, D.G. Use of Soy-Based Formulas and Cow's Milk Allergy: Lights and Shadows. *Front. Pediatr.* **2020**, *8*, 591988. [CrossRef]
45. Miller, C.J.; Dickstein, J. Jain Veganism: Ancient Wisdom, New Opportunities. *Religions* **2021**, *12*, 512. [CrossRef]
46. Munekata, P.E.S.; Domínguez, R.; Budaraju, S.; Roselló-Soto, E.; Barba, F.J.; Mallikarjunan, K.; Roohinejad, S.; Lorenzo, J.M. Effect of Innovative Food Processing Technologies on the Physicochemical and Nutritional Properties and Quality of Non-Dairy Plant-Based Beverages. *Foods* **2020**, *9*, 288. [CrossRef]
47. Giacalone, D.; Clausen, M.P.; Jaeger, S.R. Understanding Barriers to Consumption of Plant-Based Foods and Beverages: Insights from Sensory and Consumer Science. *Curr. Opin. Food Sci.* **2022**, *48*, 100919. [CrossRef]
48. Maryniak, N.Z.; Sancho, A.I.; Hansen, E.B.; Bøgh, K.L. Alternatives to Cow's Milk-Based Infant Formulas in the Prevention and Management of Cow's Milk Allergy. *Foods* **2022**, *11*, 926. [CrossRef]
49. Balogh-Hartmann, F.; Páger, C.; Bufa, A.; Horváth, I.M.; Verzár, Z.; Marosvölgyi, T.; Makszin, L. Microfluidic Analysis for the Determination of Protein Content in Different Types of Plant-Based Drinks. *Molecules* **2023**, *28*, 6684. [CrossRef] [PubMed]
50. Xie, A.; Dong, Y.; Liu, Z.; Li, Z.; Shao, J.; Li, M.; Yue, X. A Review of Plant-Based Drinks Addressing Nutrients, Flavor, and Processing Technologies. *Foods* **2023**, *12*, 3952. [CrossRef] [PubMed]
51. Szilagyi, A.; Ishayek, N. Lactose Intolerance, Dairy Avoidance, and Treatment Options. *Nutrients* **2018**, *10*, 1994. [CrossRef] [PubMed]

52. United Nations Department of Economic and Social Affairs. Sustainable Development. The 17 Goals. Available online: https://sdgs.un.org/goals (accessed on 12 January 2024).
53. EFSA Panel on Dietetic Products; Nutrition and Allergies (NDA). Scientific Opinion on the Evaluation of Allergenic Foods and Food Ingredients for Labelling Purposes. *EFSA J.* **2014**, *12*, 3894. [CrossRef]
54. Jeske, S.; Zannini, E.; Arendt, E.K. Past, Present and Future: The Strength of Plant-Based Dairy Substitutes Based on Gluten-Free Raw Materials. *Food Res. Int.* **2018**, *110*, 42–51. [CrossRef]
55. Fiocchi, A.; Brozek, J.; Schünemann, H.; Bahna, S.L.; von Berg, A.; Beyer, K.; Bozzola, M.; Bradsher, J.; Compalati, E.; Ebisawa, M.; et al. World Allergy Organization (WAO) Diagnosis and Rationale for Action against Cow's Milk Allergy (DRACMA) Guidelines. *Pediatr. Allergy Immunol.* **2010**, *21*, 1–125. [CrossRef]
56. Wolf, C.A.; Malone, T.; McFadden, B.R. Beverage Milk Consumption Patterns in the United States: Who Is Substituting from Dairy to Plant-Based Beverages? *J. Dairy Sci.* **2020**, *103*, 11209–11217. [CrossRef]
57. Modlinska, K. Food Neophobia. In *Encyclopedia of Animal Cognition and Behavior*; Vonk, J., Shackelford, T.K., Eds.; Springer International Publishing: Cham, Switzerland, 2022; pp. 2778–2780. ISBN 978-3-319-55064-0.
58. Innova Market Insights. Top Food Trends in Europe. 2026. Available online: https://www.innovamarketinsights.com/trends/top-food-trends-2026-in-europe-market-insights-innovation/ (accessed on 26 March 2026).
59. Scholz-Ahrens, K.E.; Ahrens, F.; Barth, C.A. Nutritional and Health Attributes of Milk and Milk Imitations. *Eur. J. Nutr.* **2020**, *59*, 19–34. [CrossRef]
60. Rachtan-Janicka, J.; Gajewska, D.; Szajewska, H.; Włodarek, D.; Weker, H.; Wolnicka, K.; Wiśniewska, K.; Socha, P.; Hamulka, J. The Role of Plant-Based Beverages in Nutrition: An Expert Opinion. *Nutrients* **2025**, *17*, 1562. [CrossRef]
61. Hidalgo-Fuentes, B.; De Jesús-José, E.; Cabrera-Hidalgo, A.D.J.; Sandoval-Castilla, O.; Espinosa-Solares, T.; González-Reza, R.M.; Zambrano-Zaragoza, M.L.; Liceaga, A.M.; Aguilar-Toalá, J.E. Plant-Based Fermented Beverages: Nutritional Composition, Sensory Properties, and Health Benefits. *Foods* **2024**, *13*, 844. [CrossRef]
62. Qamar, S.; Manrique, Y.J.; Parekh, H.; Falconer, J.R. Nuts, Cereals, Seeds and Legumes Proteins Derived Emulsifiers as a Source of Plant Protein Beverages: A Review. *Crit. Rev. Food Sci. Nutr.* **2020**, *60*, 2742–2762. [CrossRef]
63. Huang, W.; Dong, A.; Pham, H.T.; Zhou, C.; Huo, Z.; Wätjen, A.P.; Prakash, S.; Bang-Berthelsen, C.H.; Turner, M.S. Evaluation of the Fermentation Potential of Lactic Acid Bacteria Isolated from Herbs, Fruits and Vegetables as Starter Cultures in Nut-Based Milk Alternatives. *Food Microbiol.* **2023**, *112*, 104243. [CrossRef]
64. Machado, A.L.B.; Silva, K.S.; Miranda, B.M.; Cardoso, C.F.; Silva, F.A.D.; Freitas, F.F. Development and Characterization of a Nut-Based Beverage of Brazil Nut (*Bertholletia excelsa*) and Macadamia (*Macadamia integrifolia*). *Food Sci. Technol.* **2024**, *44*, e02223. [CrossRef]
65. Comak Gocer, E.M.; Koptagel, E. Production of Milks and Kefir Beverages from Nuts and Certain Physicochemical Analysis. *Food Chem.* **2023**, *402*, 134252. [CrossRef]
66. Pazzanese, A.; Tagliamonte, S.; Aponte, M.; Blaiotta, G.; Chiacchio, M.F.; Khanal, P.; Vitaglione, P. Chemical and Functional Properties of Chickpea (*Cicer arietinum* L.)-Based Fermented Beverages Produced Using Different Lactic Acid Bacteria. *Foods* **2026**, *15*, 523. [CrossRef]
67. Rincon, L.; Braz Assunção Botelho, R.; De Alencar, E.R. Development of Novel Plant-Based Milk Based on Chickpea and Coconut. *LWT* **2020**, *128*, 109479. [CrossRef]
68. Duarte, C.M.; Mota, J.; Assunção, R.; Martins, C.; Ribeiro, A.C.; Lima, A.; Raymundo, A.; Nunes, M.C.; Ferreira, R.B.; Sousa, I. New Alternatives to Milk From Pulses: Chickpea and Lupin Beverages With Improved Digestibility and Potential Bioactivities for Human Health. *Front. Nutr.* **2022**, *9*, 852907. [CrossRef] [PubMed]
69. Carbajal-Padilla, D.; Sosa-Morales, M.E.; Cerón-García, A.; Morales-De La Peña, M.; Gómez-Salazar, J.A. Effect of Oat and Chickpea Content on the Physicochemical, Bioactive, and Sensory Properties of a Plant-Based Beverage during Chilled Storage. *ACS Food Sci. Technol.* **2025**, *5*, 942–952. [CrossRef]
70. Yakum, K.N.; Ariahu, C.C.; Ariahu, E.C.; Igoli, J.O. Physicochemical Properties of Fortified Coconut Milk Based Chocolate—Like Drinks as Influenced by Cocoa Powder and Sugar Levels. *Am. J. Food Sci. Technol.* **2024**, *3*, 19–29. [CrossRef]
71. Gorman, M.; Moss, R.; McSweeney, M.B. Sensory Perception of Ice Cream and Plant-Based Alternatives Evaluated Blinded and with Ingredient Lists. *Food Humanit.* **2023**, *1*, 1267–1273. [CrossRef]
72. Burhan, A.R.; Firmansyah, F. Corn Milk Yoghurt: Nutritional Composition Analysis Based On Fermentation Starter Variatons. *J. Agric.* **2025**, *4*, 210–222. [CrossRef]
73. Ateteallah, A.H.; Elkot, W.F.; Abd-Alla, A.A. Physicochemical, Antioxidant, Microstructure, Textural, and Organoleptic Characteristics of Soft Cheese Incorporated Corn Milk. *Food Process. Preserv.* **2022**, *46*, e16694. [CrossRef]
74. Shiekh, K.A.; Luanglaor, T.; Hanprerakriengkrai, N.; Jafari, S.; Kijpatanasilp, I.; Asadatorn, N.; Worobo, R.W.; Bekhit, A.E.-D.A.; Assatarakul, K. Antioxidants and Quality Changes of Thermally Processed Purple Corn (Zea Mays L.) Milk Fortified with Low Sucrose Content during Cold Storage. *Foods* **2023**, *12*, 277. [CrossRef] [PubMed]

75. Atalar, I.; Kurt, A.; Gul, O.; Yazici, F. Improved Physicochemical, Rheological and Bioactive Properties of Ice Cream: Enrichment with High Pressure Homogenized Hazelnut Milk. *Int. J. Gastron. Food Sci.* **2021**, *24*, 100358. [CrossRef]
76. Şen, L.; Okur, S. Effect of Hazelnut Type, Hydrocolloid Concentrations and Ultrasound Applications on Physicochemical and Sensory Characteristics of Hazelnut-Based Milks. *Food Chem.* **2023**, *402*, 134288. [CrossRef]
77. Camacho-Teodocio, J.D.; Gallardo-Velázquez, T.; Osorio-Revilla, G.; Castañeda-Pérez, E.; Velázquez-Contreras, C.; Cornejo-Mazón, M.; Hernández-Martínez, D.M. Macadamia (Macadamia Integrifolia) Nut-Based Beverage: Physicochemical Stability and Nutritional and Antioxidant Properties. *Beverages* **2024**, *10*, 58. [CrossRef]
78. Babolanimogadam, N.; Gandomi, H.; Akhondzadeh Basti, A.; Taherzadeh, M.J. Nutritional, Functional, and Sensorial Properties of Oat Milk Produced by Single and Combined Acid, Alkaline, A-amylase, and Sprouting Treatments. *Food Sci. Nutr.* **2023**, *11*, 2288–2297. [CrossRef]
79. Kulczyk, E.; Drozłowska-Sobieraj, E.; Bartkowiak, A. Novel Milk Substitute Based on Pea, Bean and Sunflower Seeds with Natural Bioactive Stabilisers. *Plants* **2023**, *12*, 2303. [CrossRef]
80. Seifu, Y.; Birhanu, T.; Abera, B.; Duraisamy, R. Peanut, Oat, and Chickpea Composite Plant-Based Milk Alternatives: Formulation, Optimization, and Evaluation of Nutritional, Microbial, and Shelf-Life Characteristics. *Appl. Food Res.* **2025**, *5*, 101035. [CrossRef]
81. Mertdinç, Z.; Aydar, E.F.; Kadı, İ.H.; Demircan, E.; Koca Çetinkaya, S.; Özçelik, B. A New Plant-Based Milk Alternative of Pistacia Vera Geographically Indicated in Türkiye: Antioxidant Activity, in Vitro Bio-Accessibility, and Sensory Characteristics. *Food Biosci.* **2023**, *53*, 102731. [CrossRef]
82. Reale, A.; Puppo, M.C.; Boscaino, F.; Garzon, A.G.; Drago, S.R.; Marulo, S.; Di Renzo, T. Development and Evaluation of a Fermented Pistachio-Based Beverage Obtained by Colloidal Mill. *Foods* **2024**, *13*, 2342. [CrossRef]
83. Di Renzo, T.; Osimani, A.; Marulo, S.; Cardinali, F.; Mamone, G.; Puppo, C.; Garzón, A.G.; Drago, S.R.; Laurino, C.; Reale, A. Insight into the Role of Lactic Acid Bacteria in the Development of a Novel Fermented Pistachio (*Pistacia vera* L.) Beverage. *Food Biosci.* **2023**, *53*, 102802. [CrossRef]
84. Ramos, I.M.; Manzano, P.; Poveda, J.M. Sustainable Plant-Based Milk Analogs from Pistachio, Lupin and Almond: A Zero-Waste Approach with Improved Quality Attributes. *LWT* **2026**, *245*, 119223. [CrossRef]
85. Kohajdová, Z.; Holkovičová, T.; Minarovičová, L.; Lauková, M.; Hojerová, J.; Greif, G.; Ťažká, D. Potential of Quinoa for Production of New Non-Dairy Beverages with Reduced Glycemic Index. *J. Microbiol. Biotechnol. Food Sci.* **2023**, *12*, e9885. [CrossRef]
86. El-Sohaimy, S.A.; Mehany, T.; Shehata, M.G.; Zeitoun, A.A.; Alharbi, H.M.; Alwutayd, K.M.; Zeitoun, M.A.M. Optimizing Functional, Stability, and Sensory Attributes of Quinoa Beverages through Bioprocessing, Ultrasonication, and Hydrocolloids. *Food Chem. X* **2025**, *30*, 102923. [CrossRef]
87. Zhao, L.; Liao, J.; Wang, T.; Zhao, H. Enhancement of Nutritional Value and Sensory Characteristics of Quinoa Fermented Milk via Fermentation with Specific Lactic Acid Bacteria. *Foods* **2025**, *14*, 1406. [CrossRef]
88. Goonathilaka, P.D.S.A.; Abeysundara, P.D.A.; Jayasinghe, M.A. Development of a Value Added Rice Milk by Utilizing Selected Traditional and Improved Rice Varieties in Sri Lanka. *Food Chem. Adv.* **2023**, *2*, 100319. [CrossRef]
89. Najman, K.; Ponikowska, P.; Sadowska, A.; Hallmann, E.; Wasiak-Zys, G.; Świderski, F.; Buczak, K. Physicochemical Properties and Nutritional Relevance of Rice Beverages Available on the Market. *Appl. Sci.* **2024**, *14*, 9150. [CrossRef]
90. Abou Ayana, I.A.A.; Al-Otibi, F.O.; Elgarhy, M.R.; Omar, M.M.; EL-Abbassy, M.Z.; Khalifa, S.A.; Helmy, Y.A.; Saber, W.I.A. Chemical, Physical, Microbial, and Sensory Properties of Innovative Sesame Milk Kefir, Focusing on the Ultrastructure of Kefir Grains. *ACS Omega* **2025**, *10*, 7752–7769. [CrossRef]
91. Quasem, J.M. Development of Vegetable Based Milk from Decorticated Sesame (*Sesamum indicum*). *Am. J. Appl. Sci.* **2009**, *6*, 888–896. [CrossRef]
92. Dar, S.N.; Khalid, A.; Aslam, T.; Ahsan, S.; Sadaqat, M.; Batool, C. Development of Plant-Based Milk by Combining Sesame Seeds, Pumpkin Seeds, Mango-Flavored Sesame, and Dates Flavored Sesame: Plant-Based Milk by Combining Sesame and Pumpkin Seeds. *FBT* **2025**, *5*, 51–56. [CrossRef]
93. Ahsan, S.; Khaliq, A.; Chughtai, M.F.J.; Nadeem, M.; Din, A.A.; Hlebová, M.; Rebezov, M.; Khayrullin, M.; Mikolaychik, I.; Morozova, L.; et al. Functional Exploration of Bioactive Moieties of Fermented and Non-fermented Soy Milk with Reference to Nutritional Attributes. *J. Microbiol. Biotechnol. Food Sci.* **2020**, *10*, 145–149. [CrossRef]
94. De, B.; Shrivastav, A.; Das, T.; Goswami, T.K. Physicochemical and Nutritional Assessment of Soy Milk and Soymilk Products and Comparative Evaluation of Their Effects on Blood Gluco-Lipid Profile. *Appl. Food Res.* **2022**, *2*, 100146. [CrossRef]
95. Giugliano, R.; Musolino, N.; Ciccotelli, V.; Ferraris, C.; Savio, V.; Vivaldi, B.; Ercolini, C.; Bianchi, D.M.; Decastelli, L. Soy, Rice and Oat Drinks: Investigating Chemical and Biological Safety in Plant-Based Milk Alternatives. *Nutrients* **2023**, *15*, 2258. [CrossRef]
96. Tangyu, M.; Fritz, M.; Ye, L.; Aragão Börner, R.; Morin-Rivron, D.; Campos-Giménez, E.; Bolten, C.J.; Bogicevic, B.; Wittmann, C. Co-Cultures of Propionibacterium Freudenreichii and Bacillus Amyloliquefaciens Cooperatively Upgrade Sunflower Seed Milk to High Levels of Vitamin B12 and Multiple Co-Benefits. *Microb. Cell Fact.* **2022**, *21*, 48. [CrossRef]

97. Shalabi, O.M.A.K. Utilizing Tiger Nut Milk to Make a Novel, Healthy, Functional Ice Milk. *Ann. Agric. Sci.* **2023**, *68*, 118–125. [CrossRef]
98. Clemente-Villalba, J.; Cano-Lamadrid, M.; Issa-Issa, H.; Hurtado, P.; Hernández, F.; Carbonell-Barrachina, Á.A.; López-Lluch, D. Comparison on Sensory Profile, Volatile Composition and Consumer's Acceptance for PDO or Non-PDO Tigernut (*Cyperus esculentus* L.) Milk. *LWT* **2021**, *140*, 110606. [CrossRef]
99. Ismail, H.A.; Salama, W.M.; Ali, A.A.; Awad, R.A. Impact of Tiger Nut Milk as a Substitute for Cow Milk on the Rheological, Physiochemical, and Organoleptic Properties of Functional Ice Cream. *J. Food Sci. Technol.* **2025**, *62*, 1537–1546. [CrossRef] [PubMed]
100. Penha, C.B.; Santos, V.D.P.; Speranza, P.; Kurozawa, L.E. Plant-Based Beverages: Ecofriendly Technologies in the Production Process. *Innov. Food Sci. Emerg. Technol.* **2021**, *72*, 102760. [CrossRef]
101. Rustom, I.Y.S.; López-Leiva, M.H.; Nair, B.M. Nutritional, Sensory and Physicochemical Properties of Peanut Beverage Sterilized under Two Different UHT Conditions. *Food Chem.* **1996**, *56*, 45–53. [CrossRef]
102. Matos, J.S.; Azevedo, P.Z.; Costa, J.E.G.; Justino, H.d.F.M.; Lamarão, C.V.; Sanches, E.A.; Bezerra, J.d.A.; Stringheta, P.C.; Martins, E.; Campelo, P.H. UHT Processing in the Context of Plant-Based Beverages: A Scientific Review on Product Characteristics and the Functional Role of Plant Proteins. *Food Chem. Adv.* **2024**, *5*, 100848. [CrossRef]
103. Bartula, K.; Begley, M.; Latour, N.; Callanan, M. Growth of Food-Borne Pathogens *Listeria* and *Salmonella* and Spore-Forming *Paenibacillus* and *Bacillus* in Commercial Plant-Based Milk Alternatives. *Food Microbiol.* **2023**, *109*, 104143. [CrossRef] [PubMed]
104. Morales-de la Peña, M.; Arredondo-Ochoa, T.; Welti-Chanes, J.; Martín-Belloso, O. Application of Moderate Intensity Pulsed Electric Fields in Red Prickly Pears and Soymilk to Develop a Plant-Based Beverage with Potential Health-Related Benefits. *Innov. Food Sci. Emerg. Technol.* **2023**, *88*, 103421. [CrossRef]
105. Roobab, U.; Abida, A.; Chacha, J.S.; Athar, A.; Madni, G.M.; Ranjha, M.M.A.N.; Rusu, A.V.; Zeng, X.-A.; Aadil, R.M.; Trif, M. Applications of Innovative Non-Thermal Pulsed Electric Field Technology in Developing Safer and Healthier Fruit Juices. *Molecules* **2022**, *27*, 4031. [CrossRef]
106. Morales-de la Peña, M.; Miranda-Mejía, G.A.; Martín-Belloso, O. Recent Trends in Fermented Beverages Processing: The Use of Emerging Technologies. *Beverages* **2023**, *9*, 51. [CrossRef]
107. Sampedro, F.; Geveke, D.J.; Fan, X.; Rodrigo, D.; Zhang, Q.H. Shelf-Life Study of an Orange Juice–Milk Based Beverage after PEF and Thermal Processing. *J. Food Sci.* **2009**, *74*, S107–S112. [CrossRef]
108. Akhi, A.; Rana, M.R.; Islam, N.; Ahmed, T. Nonthermal Technologies in Plant-Based Alternative Processing: Applications, Challenges, and Future Perspectives. *J. Food Process. Preserv.* **2025**, *2025*, 4986605. [CrossRef]
109. Sardão, R.; Amaral, R.A.; Alexandre, E.M.C.; Saraiva, J.A.; Pintado, M. Effect of High-Pressure Processing to Improve the Safety and Quality of a *Quercus* Acorn Beverage. *LWT* **2021**, *149*, 111858. [CrossRef]
110. Raja, A.D.R.N.; Utama, G.L.; Sikin, A.M.; Lee, A.T.; Andoyo, R. Non-Thermal Processing (NTP) as Preservation Techniques for Microbial Safety in Selected Plant-Based Food Products: A Systematic Review. *J. Food Process. Preserv.* **2025**, *2025*, 6677975. [CrossRef]
111. Chiozzi, V.; Agriopoulou, S.; Varzakas, T. Advances, Applications, and Comparison of Thermal (Pasteurization, Sterilization, and Aseptic Packaging) against Non-Thermal (Ultrasounds, UV Radiation, Ozonation, High Hydrostatic Pressure) Technologies in Food Processing. *Appl. Sci.* **2022**, *12*, 2202. [CrossRef]
112. Bhargava, N.; Mor, R.S.; Kumar, K.; Sharanagat, V.S. Advances in Application of Ultrasound in Food Processing: A Review. *Ultrason. Sonochemistry* **2021**, *70*, 105293. [CrossRef] [PubMed]
113. Sotelo-Lara, D.M.; Amador-Espejo, G.G.; Álvarez-Araiza, D.F.; Cordero-Rivera, A.K.; Millán-Quintero, K.G.; Campos-Vega, R.; Velázquez-Estrada, R.M. Ultrasound and Thermosonication as Promising Technologies for Processing Plant-Based Beverages: A Review. *Food Technol. Biotechnol.* **2024**, *62*, 538–552. [CrossRef]
114. Salve, A.R.; Pegu, K.; Arya, S.S. Comparative Assessment of High-Intensity Ultrasound and Hydrodynamic Cavitation Processing on Physico-Chemical Properties and Microbial Inactivation of Peanut Milk. *Ultrason. Sonochemistry* **2019**, *59*, 104728. [CrossRef]
115. Maghsoudlou, Y.; Alami, M.; Mashkour, M.; Shahraki, M.H. Optimization of Ultrasound-Assisted Stabilization and Formulation of Almond Milk. *J. Food Process. Preserv.* **2016**, *40*, 828–839. [CrossRef]
116. Food and Agriculture Organization of the United Nations (FAO); World Trade Organization (WTO). *Trade and Food Standards*; FAO: Rome, Italy; WTO: Geneva, Switzerland, 2017; ISBN 978-92-5-109793-9.
117. Dwinger, R.H.; De Smet, K. Legal Requirements for Food Hygiene. In *Encyclopedia of Food and Health*; Elsevier: Amsterdam, The Netherlands, 2016; pp. 529–538. ISBN 978-0-12-384953-3.
118. U.S. Food and Drug Administration. Plant-Based Milk and Animal Food Alternatives. U.S. Food and Drug Administration, 2026. Available online: https://www.fda.gov/food/nutrition-food-labeling-and-critical-foods/plant-based-milk-and-animal-food-alternatives (accessed on 30 March 2026).
119. U.S. Food and Drug Administration. *Labeling of Plant-Based Alternatives to Animal-Derived Foods: Draft Guidance for Industry*; FDA: Silver Spring, MD, USA, 2025. Available online: https://www.fda.gov/media/184810/download (accessed on 30 March 2026).

120. European Parliament and Council of the European Union. Regulation (EU) No 1308/2013 of the European Parliament and of the Council of 17 December 2013 establishing a common organisation of the markets in agricultural products (Annex VII, Part III). *Off. J. Eur. Union* **2013**, *347*, 671–854. Available online: https://eur-lex.europa.eu/eli/reg/2013/1308/oj/eng (accessed on 30 March 2026).
121. European Parliament and Council of the European Union 2010. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:336:FULL:EN:PDF (accessed on 29 March 2026).
122. Kranjc, K.; Majhenič, A.Č.; Žontar, T.P. Consumption Habits and Perception of Plant-Based Milk and Dairy Alternatives among Vegetarians and Omnivores: A Case Study of Consumers in Slovenia. *Foods* **2026**, *15*, 961. [CrossRef]
123. European Parliament and Council of the European Union. Regulation (EC) No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods. *Off. J. Eur. Union* **2006**, *404*, 9. Available online: https://eur-lex.europa.eu/eli/reg/2006/1924/oj/eng (accessed on 30 March 2026).
124. European Parliament and Council of the European Union. Regulation (EC) No 1925/2006 of the European Parliament and of the Council of 20 December 2006 on the addition of vitamins and minerals and of certain other substances to foods. *Off. J. Eur. Union* **2006**, *404*, 26. Available online: https://eur-lex.europa.eu/eli/reg/2006/1925/oj/eng (accessed on 30 March 2026).
125. Brazil National Health Surveillance Agency (ANVISA), General Food Management. *Plant-Based Foods: Report of Virtual Workshops to Identify the Regulatory Problem and Affected Agents; September 2022*; Agência Nacional de Vigilância Sanitária Gerência-Geral de Alimentos: Brasília, Brazil, 2022; p. 12. Available online: https://www.gov.br/anvisa/pt-br/assuntos/noticias-anvisa/2022/Relatoriodasoficinasparaidentificacaodoproblemaregulatorio150922.pdf (accessed on 30 March 2026).
126. Agência Nacional de Vigilância Sanitária (ANVISA). *Resolução da Diretoria Colegiada—RDC No. 726, de 1 de Julho de 2022; Dispõe Sobre os Requisitos Sanitários dos Cogumelos Comestíveis, dos Produtos de Frutas e dos Produtos de Vegetais*; Ministério da Saúde: Brasília, Brasil, 2022. Available online: https://anvisalegis.datalegis.net/action/UrlPublicasAction.php?acao=abrirAtoPublico&num_ato=00000726&sgl_tipo=RDC&sgl_orgao=RDC/DC/ANVISA/MS&vlr_ano=2022&seq_ato=002&cod_modulo=310&cod_menu=9434 (accessed on 29 May 2026).
127. Pereira, C.G.; Moreira, R.E.C.; Afonso, P.A.; Silva, A.R.C.S.; Palhares, M.d.P.P.e.; de Souza, S.V.C.; Anastácio, L.R. Plant-Based Products: Analysis of International Regulations and Strategies Used for Designation and Labeling in Brazil. *LWT* **2024**, *200*, 115980. [CrossRef]
128. Wyma, N.; Klapp, A.-L.; Nhlapo, P.; Ubanwa, M.; Niesing, C. Food-Based Dietary Guidelines in Africa and Their Inclusivity of Plant-Based Dietary Patterns. *S. Afr. J. Sci.* **2025**, *121*, 1–8. [CrossRef] [PubMed]
129. Rifky, A.L.M. Labeling Requirements for Plant Protein Sources. In *The Future of Plant Protein: Innovations, Challenges, and Opportunities*; Younis, K., Yousuf, O., Eds.; Springer Nature: Singapore, 2025; pp. 209–229. [CrossRef]
130. Vanga, S.K.; Raghavan, V. How Well Do Plant Based Alternatives Fare Nutritionally Compared to Cow's Milk? *J. Food Sci. Technol.* **2018**, *55*, 10–20. [CrossRef]
131. Moore, S.S.; Costa, A.; Pozza, M.; Vamerali, T.; Niero, G.; Censi, S.; De Marchi, M. How Animal Milk and Plant-Based Alternatives Diverge in Terms of Fatty Acid, Amino Acid, and Mineral Composition. *npj Sci. Food* **2023**, *7*, 50. [CrossRef] [PubMed]
132. Kudrina, M.; Kogevnikova, I.; Khudyakova, N. Nutritional Value of Cow's Milk. *Bull. KSAU* **2025**, *12*, 229–236. [CrossRef]
133. Fructuoso, I.; Romão, B.; Han, H.; Raposo, A.; Ariza-Montes, A.; Araya-Castillo, L.; Zandonadi, R.P. An Overview on Nutritional Aspects of Plant-Based Beverages Used as Substitutes for Cow's Milk. *Nutrients* **2021**, *13*, 2650. [CrossRef]
134. McClements, D.J. Development of Next-Generation Nutritionally Fortified Plant-Based Milk Substitutes: Structural Design Principles. *Foods* **2020**, *9*, 421. [CrossRef] [PubMed]
135. Zhang, J.; Cai, Q.; Ji, W. Nutritional Composition of Plant Protein Beverages on China's Online Market: A Cross-Sectional Analysis. *Nutrients* **2023**, *15*, 2701. [CrossRef] [PubMed]
136. Smith, N.W.; Dave, A.C.; Hill, J.P.; McNabb, W.C. Nutritional Assessment of Plant-Based Beverages in Comparison to Bovine Milk. *Front. Nutr.* **2022**, *9*, 957486. [CrossRef]
137. Craig, W.J.; Fresán, U. International Analysis of the Nutritional Content and a Review of Health Benefits of Non-Dairy Plant-Based Beverages. *Nutrients* **2021**, *13*, 842. [CrossRef]
138. Moshtaghian, H.; Hallström, E.; Bianchi, M.; Bryngelsson, S. Nutritional Profile of Plant-Based Dairy Alternatives in the Swedish Market. *Curr. Res. Food Sci.* **2024**, *8*, 100712. [CrossRef] [PubMed]
139. Zhang, Y.Y.; Hughes, J.; Grafenauer, S. Got Mylk? The Emerging Role of Australian Plant-Based Milk Alternatives as A Cow's Milk Substitute. *Nutrients* **2020**, *12*, 1254. [CrossRef]
140. Moroz, I.; Shemet, V.; Dudarev, I.; Hulai, O. Comparison of Properties of Plant-Based Milk and Cow's Milk. *SWNUFT* **2024**, *30*, 152–163. [CrossRef]
141. Lo Turco, V.; Sgrò, B.; Albergamo, A.; Nava, V.; Rando, R.; Potortì, A.G.; Di Bella, G. Assessment of the Accuracy of Nutrition Label and Chemical Composition of Plant-Based Milks Available on the Italian Market. *Foods* **2023**, *12*, 3207. [CrossRef]
142. Martínez-Padilla, E.; Li, K.; Blok Frandsen, H.; Skejovic Joehnke, M.; Vargas-Bello-Pérez, E.; Lykke Petersen, I. In Vitro Protein Digestibility and Fatty Acid Profile of Commercial Plant-Based Milk Alternatives. *Foods* **2020**, *9*, 1784. [CrossRef]

143. Angelino, D.; Rosi, A.; Vici, G.; Dello Russo, M.; Pellegrini, N.; Martini, D.; on behalf of the SINU Young Working Group. Nutritional Quality of Plant-Based Drinks Sold in Italy: The Food Labelling of Italian Products (FLIP) Study. *Foods* **2020**, *9*, 682. [CrossRef] [PubMed]
144. Clegg, M.E.; Tarrado Ribes, A.; Reynolds, R.; Kliem, K.; Stergiadis, S. A Comparative Assessment of the Nutritional Composition of Dairy and Plant-Based Dairy Alternatives Available for Sale in the UK and the Implications for Consumers' Dietary Intakes. *Food Res. Int.* **2021**, *148*, 110586. [CrossRef]
145. De La Fuente-Carmelino, L.; Anticona, M.; Ramos-Escudero, F.; Casimiro-Gonzales, S.; Muñoz, A.M. Commercial Plant-Based Functional Beverages: A Comparative Study of Nutritional Composition and Bioactive Compounds. *Beverages* **2025**, *11*, 26. [CrossRef]
146. Pandey, A.; Kamran, F.; Choudhury, M.; Li, L.; Rahman, M.S.; Hussain, M.A. Omega-3 Fatty Acid Fortification of Plant-Based Beverages to Enhance Their Nutritional Profile. *Foods* **2025**, *14*, 1602. [CrossRef]
147. Aydar, E.F.; Tutuncu, S.; Ozcelik, B. Plant-Based Milk Substitutes: Bioactive Compounds, Conventional and Novel Processes, Bioavailability Studies, and Health Effects. *J. Funct. Foods* **2020**, *70*, 103975. [CrossRef]
148. Vieira, E.F.; Souza, S. Formulation Strategies for Improving the Stability and Bioavailability of Vitamin D-Fortified Beverages: A Review. *Foods* **2022**, *11*, 847. [CrossRef]
149. Berry Ottaway, P. Fortification of Beverages with Vitamins and Minerals. In *Functional and Speciality Beverage Technology*; Elsevier: Amsterdam, The Netherlands, 2009; pp. 71–91. ISBN 978-1-84569-342-8.
150. Zhou, H.; Liu, J.; Dai, T.; Muriel Mundo, J.L.; Tan, Y.; Bai, L.; McClements, D.J. The Gastrointestinal Fate of Inorganic and Organic Nanoparticles in Vitamin D-Fortified Plant-Based Milks. *Food Hydrocoll.* **2021**, *112*, 106310. [CrossRef]
151. Zhou, H.; Zheng, B.; Zhang, Z.; Zhang, R.; He, L.; McClements, D.J. Fortification of Plant-Based Milk with Calcium May Reduce Vitamin D Bioaccessibility: An In Vitro Digestion Study. *J. Agric. Food Chem.* **2021**, *69*, 4223–4233. [CrossRef]
152. Magwere, A.A.; Keast, R.; Gamlath, S.; Nandorfy, D.E.; Pematilleke, N.; Gambetta, J.M. A Comparative Study of the Sensory and Physicochemical Properties of Cow Milk and Plant-Based Milk Alternatives. *J. Food Sci.* **2025**, *90*, e70370. [CrossRef] [PubMed]
153. Reyes-Jurado, F.; Soto-Reyes, N.; Dávila-Rodríguez, M.; Lorenzo-Leal, A.C.; Jiménez-Munguía, M.T.; Mani-López, E.; López-Malo, A. Plant-Based Milk Alternatives: Types, Processes, Benefits, and Characteristics. *Food Rev. Int.* **2023**, *39*, 2320–2351. [CrossRef]
154. Liu, H.; Xu, X.; Cui, H.; Xu, J.; Yuan, Z.; Liu, J.; Li, C.; Li, J.; Zhu, D. Plant-Based Fermented Beverages and Key Emerging Processing Technologies. *Food Rev. Int.* **2023**, *39*, 5844–5863. [CrossRef]
155. Vilela, A.; Cosme, F.; Pinto, T. Emulsions, Foams, and Suspensions: The Microscience of the Beverage Industry. *Beverages* **2018**, *4*, 25. [CrossRef]
156. Mishra, S.; Singh, R.; Upadhyay, A.; Mishra, S.; Shukla, S. Emerging Trends in Processing for Cereal and Legume-Based Beverages: A Review. *Future Foods* **2023**, *8*, 100257. [CrossRef]
157. Patra, T.; Rinnan, Å.; Olsen, K. The Physical Stability of Plant-Based Drinks and the Analysis Methods Thereof. *Food Hydrocoll.* **2021**, *118*, 106770. [CrossRef]
158. Janssen, S.W.P.M.; Pouvreau, L.; De Vries, R.J. Commercial Plant Protein Isolates: The Effect of Insoluble Particles on Gelation Properties. *Food Hydrocoll.* **2024**, *154*, 110049. [CrossRef]
159. LaClair, C.E.; Etzel, M.R. Turbidity and Protein Aggregation in Whey Protein Beverages. *J. Food Sci.* **2009**, *74*, C526–C535. [CrossRef]
160. Ren, Y.; Jia, F.; Li, D. Ingredients, Structure and Reconstitution Properties of Instant Powder Foods and the Potential for Healthy Product Development: A Comprehensive Review. *Food Funct.* **2024**, *15*, 37–61. [CrossRef]
161. Gama, A.P.; Hung, Y.-C.; Adhikari, K. Optimization of Emulsifier and Stabilizer Concentrations in a Model Peanut-Based Beverage System: A Mixture Design Approach. *Foods* **2019**, *8*, 116. [CrossRef] [PubMed]
162. Wagoner, T.B.; Çakır-Fuller, E.; Shingleton, R.; Drake, M.; Foegeding, E.A. Viscosity Drives Texture Perception of Protein Beverages More than Hydrocolloid Type. *J. Texture Stud.* **2020**, *51*, 78–91. [CrossRef]
163. Ji, L.; Otter, D.D.; Cornacchia, L.; Sala, G.; Scholten, E. Role of Polysaccharides in Tribological and Sensory Properties of Model Dairy Beverages. *Food Hydrocoll.* **2023**, *134*, 108065. [CrossRef]
164. Rastegarpour, M.; Hakimi, H.; Chamaani, N.; Marand, M.J.; Zendeboodi, F.; Sohrabvandi, S.; Khanniri, E. Application of Various Hydrocolloids in Fruit-Based Beverages to Improve Their Properties: A Review. *Int. J. Biol. Macromol.* **2025**, *318*, 145251. [CrossRef]
165. van Gunst, A.; Roodenburg, A.J.C. Consumer Distrust about E-Numbers: A Qualitative Study among Food Experts. *Foods* **2019**, *8*, 178. [CrossRef]
166. Aschemann-Witzel, J.; Varela, P.; Peschel, A.O. Consumers' Categorization of Food Ingredients: Do Consumers Perceive Them as 'Clean Label' Producers Expect? An Exploration with Projective Mapping. *Food Qual. Prefer.* **2019**, *71*, 117–128. [CrossRef]
167. Choi, D.; Bedale, W.; Chetty, S.; Yu, J.-H. Comprehensive Review of Clean-Label Antimicrobials Used in Dairy Products. *Compr. Rev. Food Sci. Food Saf.* **2024**, *23*, e13263. [CrossRef]

168. Moreira, J.B.; de Carvalho, L.F.; Matheus, J.; Prista, C.; Raymundo, A. Algae-Based Proteins and Biomass as Clean-Label Ingredients for the Food Industry. In *Microalgae Biotechnology and Sustainable Development*; Khan, A., Alzahrani, K.A., Eds.; Springer Nature: Singapore, 2026; pp. 37–57. [CrossRef]
169. Leonard, W.; Zhang, P.; Ying, D.; Fang, Z. Surmounting the Off-Flavor Challenge in Plant-Based Foods. *Crit. Rev. Food Sci. Nutr.* **2023**, *63*, 10585–10606. [CrossRef] [PubMed]
170. George, G.S.; Fleming, C.J.; Upadhyay, R. Perspective on Oral Processing of Plant-based Beverages. *J. Texture Stud.* **2024**, *55*, e12846. [CrossRef] [PubMed]
171. Tang, Y.; Zhou, C.; Yu, Z.; Jiang, M.; Chen, Y.; Wang, H.; Yang, Z. Formation of Lipid-Derived Volatile Products through Lipoxygenase (LOX)- and Hydroperoxide Lyase (HPL)- Mediated Pathway in Oat, Barley and Soy Bean. *Food Chem. X* **2024**, *22*, 101514. [CrossRef] [PubMed]
172. Sharma, N.; Yeasmen, N.; Dube, L.; Orsat, V. Rise of Plant-Based Beverages: A Consumer-Driven Perspective. *Food Rev. Int.* **2024**, *40*, 3315–3341. [CrossRef]
173. Pua, A.; Tang, V.C.Y.; Goh, R.M.V.; Sun, J.; Lassabliere, B.; Liu, S.Q. Ingredients, Processing, and Fermentation: Addressing the Organoleptic Boundaries of Plant-Based Dairy Analogues. *Foods* **2022**, *11*, 875. [CrossRef]
174. Ammann, J.; Grande, A.; Inderbitzin, J.; Guggenbühl, B. Understanding Swiss Consumption of Plant-Based Alternatives to Dairy Products. *Food Qual. Prefer.* **2023**, *110*, 104947. [CrossRef]
175. Geburt, K.; Albrecht, E.H.; Pointke, M.; Pawelzik, E.; Gerken, M.; Traulsen, I. A Comparative Analysis of Plant-Based Milk Alternatives Part 2: Environmental Impacts. *Sustainability* **2022**, *14*, 8424. [CrossRef]
176. Food and Agriculture Organization of the United Nations (FAO). *Greenhouse Gas Emissions from Agrifood Systems: Global, Regional and Country Trends, 2000–2020*; FAOSTAT Analytical Brief Series No. 50; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2022; ISSN 2709-0078.
177. Biagetti, E.; Gislon, G.; Martella, A.; Zucali, M.; Bava, L.; Franco, S.; Sandrucci, A. Comparison of the Use of Life Cycle Assessment and Ecological Footprint Methods for Evaluating Environmental Performances in Dairy Production. *Sci. Total Environ.* **2023**, *905*, 166845. [CrossRef]
178. Buchan, L.; Henderson, A.; Unnasch, S. *Ripple Milk Life Cycle Assessment*; Life Cycle Associates Report LCA.6121.001.2022; Life Cycle Associates, LLC: Portola Valley, CA, USA, 2022; Prepared for Ripple Foods.
179. Costa, M.P.; Saget, S.; Zimmermann, B.; Petig, E.; Angenendt, E.; Rees, R.M.; Chadwick, D.; Gibbons, J.; Shrestha, S.; Williams, M.; et al. Environmental and Land Use Consequences of Replacing Milk and Beef with Plant-Based Alternatives. *J. Clean. Prod.* **2023**, *424*, 138826. [CrossRef]
180. Kovanen, I.; Kyttä, V.; Kårlund, A.; Pajari, A.-M.; Tuomisto, H.; Saarinen, M.; Kolehmainen, M. Advancing Methods for Comparative Nutritional LCA of Milk and Plant-Based Milk Substitutes. *Int. J. Life Cycle Assess.* **2025**, *30*, 462–476. [CrossRef]
181. Su, W.; Zhang, Y.Y.; Li, S.; Sheng, J. Consumers' Preferences and Attitudes towards Plant-Based Milk. *Foods* **2023**, *13*, 2. [CrossRef]
182. Plant-Based Milk Market | Global Dairy Alternatives Industry Forecast & Outlook 2036. Available online: https://www.futuremarketinsights.com/reports/plant-based-milk-market (accessed on 22 March 2026).
183. Dairy Alternatives Market Size, Share | Growth Report [2034]. Available online: https://www.fortunebusinessinsights.com/industry-reports/dairy-alternatives-market-100221 (accessed on 22 March 2026).
184. Smart Protein. What Consumers Want: A Survey on European Consumer Attitudes Towards Plant-Based Foods. European Union's Horizon 2020 Research and Innovation Programme Under Grant Agreement No 862957: Brussels, Belgium, 2021. Available online: https://smartproteinproject.eu/market-research/ (accessed on 18 March 2026).
185. Statista. Plant-Based Milk and Dairy Alternatives in Europe. 2025. Available online: https://www.statista.com/topics/10162/milk-and-dairy-alternatives-in-europe/?srsltid=AfmBOoqNqWDWW19mUofxU5d5v8_8hD10fYiJT4b8Xdi5J_p4gL30lAMM#topicOverview (accessed on 18 March 2026).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.