A review on plant-based tree nuts beverages: technological, sensory, nutritional, health and microbiological aspects

Victor Jonas da Rocha Esperança a, Caroline Corrêa de Souza Coelho a, Renata Tonon b, Renata Torrezan b, and Otniel Freitas-Silva b

aFood and Nutrition Graduate Program, Federal University of State of Rio de Janeiro (PGGAN/ UNIRIO). Av. Pasteur, Rio de Janeiro, Brasil; bCentro de Tecnologia Agrícola e Alimentar/CTAA, EMBRAPA Agroindústria de Alimentos, Av. das Américas, Rio de Janeiro, Brasil

ABSTRACT
The term tree nuts is used to describe any nut that comes from a tree. The best known and most consumed are almond, Brazil nut, cashew, hazelnut, macadamia, pecan, pine nut, pistachio, and walnut. This consumption has led to their use in the development of plant-based beverages. This review aims to bring information reported in the literature on plant-based beverages made from tree nuts regarding health, technological, microbiological, sensory, and consumer aspects. The bibliographic search covered the articles published between the years 2000 and 2022. In total, 54 articles were selected for this review, which were categorized according to their thematic area as Food technology (n = 37); Nutrition and Health (n = 19); Microbiological aspects (n = 10); and Sensory and consumer studies (n = 12). It was observed that the most mentioned tree nuts were almond, cashew, hazelnut, and walnut, and the lowest mentioned were Brazil nut, macadamia nuts, pine nut, mallow nut, and sapucaia. Finally, this review observed that beverages represent beneficial nutritional and functional profile, but cannot be considered as a substitute, in their entirety, for dairy milk, except in the case of allergies to this food. Technological aspects proved to be positive for obtaining these beverages, with high pressure being the most advantageous. Considered safe and very promising from nutritional, industrial, environmental, and functional aspects.

Introduction

From a culinary point of view, nuts can be defined as any grain used in food with a high lipid content and protected by a thick husk. From a botanical point of view, they are defined as dry fruits composed of a hard inedible husk and a seed. The term "tree nuts" is associated to describe any nut from a tree, and this can typically include foods that do not meet the traditional botanical definition. The best known and most consumed tree nuts in the world are almond, Brazil nut, cashew, hazelnut, macadamia, pecan, pine nut, pistachio, and walnut. The consumption and production of tree nuts has been increasing over the years. In the last two years, the USA and Turkey were considered the largest producers of tree nuts in the world, with both productions exceeding 200 thousand tons in this period. On the other hand, the biggest consumers-importers of tree nuts were China and the countries of the European Union (USDA, 2021). Studies point to several health benefits in the consumption of fresh tree nuts and their products: cashew; pecan; almond; Brazil nut; pistachio; hazelnut. The positive effects have been mainly associated with the lipid profile and the high mineral content of these nuts.

CONTACT Otniel Freitas-Silva, otniel.freitas@embrapa.br Embrapa Agroindústria de Alimentos. Av das Américas, 29.501, Guaratiba, Rio de Janeiro 23020-470, RJ, Brasil

© 2022 Victor Jonas da Rocha Esperança, Caroline Corrêa de Souza Coelho, Renata Tonon, Renata Torrezan and Otniel Freitas-Silva. Published with license by Taylor & Francis Group, LLC. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
Plant-based beverages are gaining great prominence in the food market, as they are considered healthy alternatives for consumption and because they present themselves as a substitute option for products traditionally made from dairy milk. Drinks in general are essential in the daily diet of human beings, as they are considered practical and accessible foods for consumption, in addition to being able to contain a large mixture of nutrients in a small volume of food.

However, some vegetable drinks may have limitations in the content of some nutrients essential to health, especially regarding the physiological needs of vulnerable groups such as children. In this sense, with the objective of offering an adequate and balanced intake of nutrients, thus avoiding nutritional deficiencies, fortified drinks are seen as a practical alternative and well accepted by the public. The fortification of fruit and vegetable drinks has been an important and positive strategy from a nutritional point of view. The technologies used for the conservation of these products must enable an improvement in the bioavailability of nutrients with preservation of physicochemical properties, stability, sensory characteristics, and acceptance by consumers. From this perspective, the increase in nutrients and bioactive compounds is seen as an improvement to the product and a benefit to the consumer, and this has been perceived in the formulation of vegetable drinks.

Studies show that vegetable drinks are emerging in worldwide consumption; however, consumers still require more information on the composition and benefit of these beverages. In this sense, this review aims to bring information reported in the literature on “plant-based” beverages made from tree nuts, regarding health, technological, microbiological, sensory, and consumer aspects.

**Methodology**

The present work consisted of a bibliographic search carried out from June to September 2021, in the following databases: “Science Direct,” “Ebsco,” “Scielo” and “Pub Med,” where the descriptors used were: “nuts AND (beverages OR drink OR extract OR plant-based OR milk) AND NOT tiger.” Articles between the years 2000–2022 were selected. For this study, only articles related to beverages/extracts made with tree nuts were included, thus excluding studies carried out exclusively on “coconut,” “peanut,” “tiger nut” and other fruits that did not fit the definition “tree nuts.” Works that used blends of “animal milk” with tree nuts were also excluded. After applying the filters and exclusion criteria, the articles were previously read (abstract and title) and the replicated ones were excluded, as shown in Figure 1.
Results

After reading and application of the exclusion and inclusion criteria, 54 articles were selected for this study, being categorized according to their thematic area as shown in Table 1. The defined thematic areas were Food technology (n = 37); Nutrition and Health (n = 19); Microbiological aspects (n = 10); Sensory and consumer study (n = 12). An article may belong to more than one established category.

Most of the articles were related to the years 2020 (22.22%), 2019 (16.66%), 2021 (16.66%), and 2018 (11.11%), with the lowest prevalence in the years 2000, 2003, 2007, 2012 and 2013 with 1.8% each. After applying the criteria, there were no recovery articles from the years 2001–02, 2004–06, 2008, 2010–11. It was observed that of the selected articles, those of the research type (n = 43) were in greater quantity than those of the review type (n = 11).

Regarding the prevalence of tree-nuts, it was found that the most mentioned in the articles were almond (n = 23), cashew (n = 19), hazelnut (n = 13) and walnut (n = 11). The lesser mentioned were Brazil nut (n = 4), macadamia (n = 4), pine nut (n = 3), mallow nut (n = 2), sapucaia (n = 2), Chilgoza pine (n = 1), tucumã almond (n = 1), Quercus acorn (n = 1), pistachios (n = 1), cupuacu almond (n = 1) and pecan (n = 1). Of the 54 articles selected, 13 presented drinks based on blends with fruits, vegetables, or other tree-nuts. Regarding these blends, it was noticed that the most mentioned ingredients for the mixture were tree-nuts (n = 4), (almond, macadamia, walnut and hazelnut), soy (n = 3), rice (n = 3), mango (n = 2), coconut (n = 1), pea (n = 1), oats (n = 1), chocolate (n = 1), prune (n = 1), passion fruit (n = 1), pineapple (n = 1), mix vegetables (n = 1), cocoa (n = 1) and carob (n = 1).

Thematic fields (FT = Food and Technology; NH = Nutrition and health; MA = Microbiology aspects; SC = Sensory and consumer studies)

Discussion

Food technology

Tree nuts beverages are foods that have complex colloidal structures in their matrix that directly affects the appearance, texture, mouthfeel, flavor, stability, and bioavailability of nutrients. Therefore, proper knowledge of these structures is essential for the preparation of plant-based beverage substitutes for dairy milk, as this knowledge can be used to improve quality and functional attributes and contribute to the healthiness of the product. Tree-nut matrices are not considered simple to manage. Their stability and rheology properties are poor when compared, for example, to animal milks and beverages or from other plants such as soybeans, which performed well in relation to hydrocolloids. In this sense, prior treatment and adequate processing, such as the use of high pressure, temperatures, pH modification, enzymes, fermentation, and homogenization are necessary to improve the solubility, stability, and maintenance of the sensory characteristics of the product during storage. The correct choice of extraction methods is also important to obtain a product with a better nutritional and bioactive profile, whether aqueous or alcoholic.

The use of high pressure was shown to be positive in the elaboration of tree-nuts beverages. A study by Valencia-Flores points out that high pressure is a potential alternative to conventional heat treatments, as it produces highly stable vegetable drinks from a microbiological, physical, and chemical point of view. Experiments by Gul et al. pointed out that high pressure processing of hazelnut milk samples increased the solubility of proteins in water, reduced the viscosity of the product. Therefore, this technology indicates a wide application for processing such products due to the improved preservation of the microstructure and rheological properties, as well as lower energy consumption and greater efficiency due to changing viscosity.

The acceptance of the rheological properties of these beverages under technological treatment may vary according to the desired product. This is shown, for example, by the study by Atalar et al., where the use of hazelnut milk under high pressure led to a high viscosity and consistency index and
| Tree nuts | Type of paper | Thematic field | Authors |
|----------|---------------|----------------|---------|
| Almond   | Research      | NH             | [31]    |
| Almond, hazelnut, walnut, cashew | Research | NH | [32] |
| Hazelnut | Research      | FT             | [33]    |
| Hazelnut | Research      | FT             | [14]    |
| Walnuts, hazelnuts | Research | NH | [34] |
| Blend soy and Brazil nut | Research | FT and MA | [35] |
| Walnut and blend soy-walnut | Research | FT and SC | [36] |
| Cashew nut | Research | MA | [37] |
| Blend Cashew nut and mango | Research | SC | [38] |
| Brazil nut | Research | FT | [39] |
| Almonds, cashews, hazelnuts, macadamia, almond and coconut, pea and almond, almond and cashew rice and hazelnut, oats and walnut, hazelnuts, walnut, and almond mix | Review | NH | [29] |
| Brazil nut | Research | MA | [40] |
| Sapucaia nut (Lecythis pisonis Cambess) | Research | FT | [41] |
| Walnut | Research | FT | [42] |
| Pine nut (Siberian Pine) | Review | FT, NH | [43] |
| Blend soy and Brazil nut | Research | FT and SC | [44] |
| Almond (Prunus dulcis), sapucaia nut (Lecythis pisonis), cashew nut (Anacardium occidentale), hazelnut (Corylus avellana) cupuaçu almond (Theobroma grandiflorum), tucumã almond (Astrocaryum tucumã), Astrocaryum gerardania (blend) | Review | NH | [45] |
| Walnut | Research | MA | [46] |
| Hazelnut | Research | FT | [47] |
| Chilgoza (Pinus gerardiana) | Research | FT | [48] |
| Almond, hazelnut | Research | FT and NH | [49] |
| Siberian Pine (Pinus sibirica Du Tour) | Research | FT and NH | [50] |
| Blend rice and Pine nut (Pinus koraiensis) | Research | FT | [51] |
| Almond | Research | FT, MA, and SC | [52] |
| Walnut | Research | FT | [53] |
| Walnut | Research | FT | [54] |
| Almond drink, chocolate almond drink, walnut drink | Research | FT | [55] |
| Almond, Cashew, Hazelnut | Research | NH | [56] |
| Cashew | Research | FT and MA | [57] |
| Almonds, cashews | Review | FT | [58] |
| Almond | Review | FT, NH, and SC | [59] |
| Cashew nut | Research | FT | [60] |
| Almond, cashew nut (flavored with cacao or carob) | Research | FT and SC | [61] |
| Almond | Research | FT and MA | [62] |
| Cashew nut (blend prune, brown rice) | Research | FT and SC | [63] |
| Malva nut | Research | NH | [64] |
| Almond, walnut and hazelnut | Review | FT | [65] |
| Cashew nut (blend passion fruit) | Research | FT and SC | [66] |
| Cashew nut (blend with pineapple juice) | Research | FT and SC | [67] |
| Cashew nut (blend mango) | Research | FT, MA, and SC | [68] |
| Pistachios | Research | FT, MA, and SC | [69] |
| Quercus acorn | Research | FT and MA | [70] |
| Almond, hazelnut | Review | NH | [71] |
| Blend Brazil nut and baru, Brazil and Macadamia | Research | FT | [72] |
| Cashew, almond | Research | NH | [73] |
| Walnut (Juglans) and two types of hazelnuts (Corylus avellana almond; Prunus dulcis) | Research | MA | [74] |
| Malva nut (Scaphium affine) | Research | NH | [75] |
| Almonds | Research | FT | [76] |
| Almond | Research | NH | [77] |
| Walnut (vegetable blend) | Research | FT and NH | [78] |
| Almonds, cashew, macadamia, pecan | Research | NH | [79] |
| Almond, Cashew, Macadamia, Hazelnut | Research | NH | [80] |
a high rigidity parameter in the product, but provided the desired textural, melting rate, and rheological improvement, as they were related to ice cream formulations.

Regarding the use of temperatures, the physicochemical properties and oxidation stability of tree nut beverages can be affected by the intensity of the heat treatment and the storage period. Therefore, choosing the right time and temperature is important to ensure improvement in the parameters of the final product. According to Atalar et al., heat treatments cause protein denaturation in these beverages, thus increasing aggregation. Therefore, samples when treated at high temperatures have a higher level of aggregation than those treated at lower temperature, thus decreasing their solubility, changing the content of soluble solids (°Brix) and increasing the viscosity of the final product, in addition to impacting the increase in the hydroperoxide index during the storage period. On the other hand, the use of negative temperatures seems to have positive effects on the storage of tree-nut extracts. In the experiment by Demoliner et al., this method proved to be a very interesting tool for obtaining and maintaining nutrients and concentrates rich in bioactive content from the extract obtained from sapucaia nut.

Heat treatment and high pressure have positive and negative effects regarding the maintenance of product quality, suggesting that these methodologies should be used as complementary in the preparation of tree nuts beverages. This concept is reinforced according to Sardão et al., who demonstrated that high pressure preserved the soluble solids content and color better than heat treatment, but heat-treated samples showed superior antioxidant activities (ABTS/DPPH) compared to samples treated with high pressure. Regarding macronutrients, the results were similar between treatments.

The bibliographical survey also pointed out fermentation as a method to improve the technological properties of tree nut-based beverages, but this process can lead to nutritional losses such as a decrease in carbohydrates, fibers, and minerals by up to 38.5% after fermentation. Another resource used to improve the stability of tree nuts beverages is the use of additives. One of the arguments that reinforces this need is that sometimes the protein content of these drinks (depending on the tree nut) is not enough to stabilize an emulsion, requiring the use of emulsifiers such as lecithin, xanthan gum and carboxymethylcellulose. However, with the application of heat treatment they can lose their technological effect, gum arabic and the use of BHT with the objective of preventing the oxidation of these beverages.

Penha et al. pointed out that for the preparation of vegetable beverages, it is necessary to apply the most efficient and viable method that will result in a final product with satisfactory physical stability and minimize the need for additives such as hydrocolloids and emulsifiers. However, Cardarelli and Oliveira, and Lee and Rhee state that the use of physical processing added to additives are important factors in determining the adequacy of processing beverages prepared with tree-nuts. A possible explanation for this small divergence in the literature is the year/time of publication, as over the years the development of products with less additives and more ecologically sustainable means are gaining notoriety and gaining demand and interest in the current market.

With regard to sustainability (ecofriendly products), vegetable drinks have great potential and have been a major trend in the modern food industry because of their environmental, health, and ethical benefits. An earlier study by McClements et al. pointed out that water consumption in the cultivation of nuts for the production of vegetable drinks was similar to that of animal milk. In this sense, two studies drew attention during the preparation of this work, as they developed beverages from tree-nuts cultivated with reduced irrigation using almonds and pistachios showing that it was possible to prepare healthy, nutritious, and environmentally friendly beverages while also saving 66% and 74% of irrigation water by way of said cultivation modality. Another relevant study on this issue was one carried out by Rebouças et al. who developed a drink that uses broken nuts with low commercial value, which contributes to greater profits in this sector and avoids food waste.

The technological processes and methodologies pointed out in this section seem to be promising within the tree nuts beverages industry. However, some important parameters at industrial levels need to be analyzed, Penha et al. state that to incorporate these alternative and innovative techniques at
an industrial level, the processes must still be evaluated according to each matrix; specifically, to verify its cost-effectiveness and feasibility, which is still a challenge for the food industry.

**Sensory aspects and consumer study**

The market and demand for plant-based beverages are growing and expressive. However, there are great challenges regarding the sensory aspect and acceptance of these products. Developing a healthy and sensory-pleasing product is not an easy task. With respect to tree nuts beverages, this situation is similar, and some resources have been used to improve the flavor in order to influence on the product acceptance.

Blending nuts, for example, has been one of the tools to improve the flavor and aroma of tree-nut drinks. The study by Pinto et al. corroborates this information and points out that blended tree nuts drinks were more accepted than drinks based on other cereals and vegetables (soy, oats, rice, quinoa) and demonstrated that it was technically possible to develop a vegetable-based beverage from brown rice, plums and cashew nut, which has high overall acceptability. Blends seem not only to have a positive impact on taste, but also on the color of the final product. Felberg et al. enhance a drink with a soy and Brazil nut blend and pointed out that this mixture contributed to a change in the product’s color (decreasing the yellow color and increasing the white color) and improved the acceptance of the product. This can be explained because most plant-based milks have a creamy appearance and their color and lightness can be significantly different from those of bovine milk, which adds to the appearance of an enhance drink.

There is still no consensus on the adequate percentage of tree nuts and the ingredients for blends. The authors, in general, point out that this can vary according to the nut and beverage made. One hypothesis is related to the different percentages of sugars in fruits and vegetables used and the lipids of nuts that can influence the perception of product palatability. In addition, the addition of other beverage formulating ingredients such as sugars can also interfere with the issue of flavor acceptance.

Fermentation was also mentioned as a tool with great potential to improve the sensory profile of these beverages. Bruno et al. used fermentation to prepare a cashew nut beverage without significant changes in color and with good sensory acceptance. However, Cunha Júnior et al. did not have the same results, as fermented Brazil nut beverages received low scores for “general acceptance” and “fermented taste,” however nut flavor and “sweetness” were equal to the unfermented Brazil nut beverages tested. These differences in results regarding flavor can be explained by a lack of standardization and combination of strains for fermentation for this purpose. Tangyu et al. conclude that strain blending is still conducted with trial-and-error approaches and that possibilities for more rational selection and blending of strains with predictable synergistic interactions would be highly valuable for developing smarter fermentation processes and better products.

Regarding sensory acceptance, almond was observed as a very versatile tree nut applicable to beverages. Qamar et al. pointed to the use of this nut in emulsions to improve flavor. One of the possible explanations for this improvement is that the perception of the general taste of almond “milk” is quite similar to that of bovine milk and consumers associate the taste with a known food, since the experimenting with new foods and flavors can lead to difficulties in accepting a product.

Morais and Rodrigues developed a drink based on almond and cashew nut to test the possible replacement of cocoa by locust bean powder, and pointed out that tree nuts were good vehicles to carry out this experiment. Sensory low scores were found by Lipan et al. in the elaboration of almond milk powder, but which, according to them, can be improved with the application of adequate techniques.

One of the possible techniques indicated for this sensory improvement is the use of the high-pressure process (HPP). The experiment by Sardão et al. showed a preference for Quercus acorn drink when treated with HPP overheat treatment. Regarding color, although both treatments showed equivalent results, HPP showed better color retention and consumers preferred this drink. In general, plant-based beverages may have inferior flavors to the traditional bovine milk beverage. Another
suggestion to overcome this problem is homogenization which modifies insoluble emulsion particles to a size larger than that detected by the tongue (usually less than about 50 µm) making the product more palatable.\[58\]

Other factors that are also relevant within consumer studies are the aspects of labels and packaging that can influence the purchase of tree nut beverages. The use of labels and different nutritional claims have a positive impact on the perception of the drink in relation to quality, general impression, and purchase intention.\[66\] Cabral Rebouças et al.\[38\] point out in their study that the most relevant qualitative information in the purchase intention was the label illustration (especially the labels with the highlighted nut figure), nutritional information (0% lactose and 0% cholesterol), and functional claim term “prebiotic.” In addition, according to these authors, the illustration itself was the biggest influence, even overlapping nutritional information and functional claims.

**Nutrition and health**

Composition and nutritional profile: Regarding the composition and nutritional richness of drinks based on tree nuts, it can be stated that there is a certain divergence in the literature regarding certain points, for example, the percentage and biological value of the product’s protein and content of micronutrients such as calcium. The study by Lipan et al.\[52\] states that a drink made with almond was a good source of Ca, K and Zn, and was rich in Mg, Cu, Mn and monounsaturated fat. In this same perspective, the works by Sardao et al.\[68\] and Atalar et al. point out that beverages made from tree nuts were a good source of minerals in general. Bolarinwa et al.\[56\] used walnut to enrich a soy-based beverage that resulted in a notable increase in protein and mineral content in the product. From this same angle, Dyshluk et al.\[43\] substituted raw milk for pine nut in the elaboration of “dairy” products and realized that they did not reduce the nutritional value of new dairy products, as they had a high proportion of protein, fat and minerals and were as rich in vitamins as their milk-based counterparts.

However, many studies indicate that tree-nuts and plant-based beverages in general are poor and inferior in nutritional content when compared to animal milk or even soy-based beverages (depending on the tree-nut).\[17,18,32,62,69,79\] This divergence within the literature can be explained by the wide variety of tree nuts, each one with a unique nutritional profile and very peculiar characteristics\[49\]; as such, to generalize them would be a mistake. This nutritional variation can be observed both in the fresh nut and in the final drink\[17,45\] and even beverages from the same nut can present variations in the countries where they are produced and marketed.\[26\] Another hypothesis that can be raised is that during the technological processing of these beverages there may be significant nutritional losses, thus reducing the nutrient profile of the final product.\[140,52\] In relation to plant-based beverages and extended to tree nuts beverages, there is a certain consensus by the aforementioned authors that these beverages can be an alternative to animal milk only in case of allergies. However, the nutritional comparisons have not presented any concise indication for such replacement. What can be said so far is that tree-nut drinks can be nutritionally rich when compared to some fruit and vegetable drinks, but in relation to animal milk and soy are at their disadvantages. However, this nutritional profile can be improved upon and should be for the fortification of tree nuts products.

Regarding the fortification and improvement of plant-based beverages, Jeske et al.\[49\] state that the choice of ingredients to improve the product must be a wiser and healthier choice than the addition of low-cost fortifiers and additives. In this sense, we can point out the studies by Pinto et al.\[62\] and Tiurikova and Peresichny,\[76\] who used blends of tree nuts and other vegetables that added nutritional, functional and biological value to the final drink, receiving good acceptance by consumers. Silva et al.\[70\] pointed out that cashew and almond beverages had less calcium than cow’s milk; however, samples that were fortified had comparable values for total calcium and more calcium bioaccessibility than cow’s milk. Craig et al.,\[29\] state that certain vitamins such as D and B12 need to receive greater attention with regard to fortification, as they are present and more bioavailable in foods of animal origin. Tree-nuts, therefore, may have a greater appeal to the vegetarian public, as they are lacking vitamins in their diet.
Such information regarding the nutritional and functional profile generates a positive impact on consumers when they intend to purchase tree nuts beverages.\textsuperscript{[17,38]} Therefore, the improvement of these products in terms of nutrient content, health benefits, and information should deserve attention and investment by industry and research.\textsuperscript{[29,59,79]} In this aspect, tree nuts beverages, depending on the nut that composes them, can present great bioactive potential regarding antioxidant activity due to their phenolic content.\textsuperscript{[50,71]} In addition, considering the functional aspect, some studies have also pointed to the possibility of successfully enriching these drinks with prebiotics.\textsuperscript{[38,64,65]}

Health benefits and risks: Regarding the immunological safety of these drinks, the literature points out that indeed certain nuts can trigger an allergic response in some patients with hypersensitivity to the nutrients that make up these foods. Masiri et al.\textsuperscript{[56]} pointed out in their study possible allergens in beverages prepared with almond, cashew, hazelnut. It is possible that an individual is allergic to one or more of these nuts, as drinks may contain mixtures of nuts, it is essential that there is specification in the labeling as to the composition so that allergic individuals can be informed about consumption.\textsuperscript{[45]}

However, it is very common for other nuts to be mixed in intentionally or unintentionally (fraud and contamination) and identifying this contamination is of paramount importance. Ding et al.\textsuperscript{[42]} established a strategy, based on DNA tracking, to detect the authenticity of tree nuts beverages in local markets in China and found that some tree-nut beverages sold in the region had been contaminated with other nuts.

Tree nuts beverages are safe to drink, with the exception of course for the public allergic to nuts. Astolfi et al.\textsuperscript{[32]} showed that these beverages are quite safe, with low contamination by toxic trace elements, including As, Cd, Hg and Pb. These beverages can also have certain health benefits such as improved blood glucose and cholesterol levels\textsuperscript{[34,63]} and dental health. A study by Townsend et al.\textsuperscript{[77]} provided evidence that fluoride concentration varies among different plant-based beverages, but with few exceptions, and that these beverages contain significantly more fluoride than cow’s milk and thus they encourage that such information be placed on labels. This is enforced by Abd-elmonsif et al.\textsuperscript{[51]} who pointed out that almond milk had good remineralization capacity and tooth enamel protection (in relation to calcium and phosphorus levels) when compared to soy, oat, bovine, and cocoa milks. However, it is necessary to emphasize that almond milk should not be sweetened with sucrose, as this way it can have a cariogenic potential.\textsuperscript{[75]}

**Microbiological aspects**

A relevant aspect to consider in the elaboration of tree nut drinks is their relationship in the human body, especially regarding the intestinal microbiota. According to McClements et al.\textsuperscript{[59]} there has been very little published research in this area and at present, there is still a relatively poor understanding of how these plant-based beverages affect the human gut (microbiota) and what long-term health implications this has for humans. They state that more research is needed and that it seems to be a very promising study topic.\textsuperscript{[58]} In this sense, studies were found in the literature on the concept of intestinal microbiota and functionality, which is the development of these beverages as a probiotic function. It is an enrichment of tree nuts beverages with microorganisms with beneficial to the intestinal health. Lipan et al.\textsuperscript{[52]} showed that it is possible to enhance a powdered almond drink enriched with *Lactobacillus plantarum*.

A point that was raised is that tree-nuts are a good substrate for the development of these functional beverages. Barbosa et al.\textsuperscript{[35]} stated that the drink made with Brazil nut was an excellent substrate for the fermentation of *Lactobacillus acidophilus*, *Bifidobacterium* and *Streptococcus thermophilus*. This information also corroborates the results of Bruno et al.\textsuperscript{[37]} who demonstrated that cashew nut milk proved to be a good matrix for *Bifidobacterium animalis*, *Lactobacillus acidophilus* and *L. plantarum*. However, another point to be evaluated is whether the beverages produced, in addition to being good substrates, present probiotic viability in the human intestine or if at least the numbers of colony-forming units are in sufficient quantities after technological processing – information that was slightly diverged in the findings. For example, Mattison et al.\textsuperscript{[67]} characterized a commercially available yogurt and found that the mean lactobacilli and *Streptococcus thermophilus* colony counts were greater than
10 M colony forming units per milliliter, indicating they could provide a beneficial bacterial health benefit. Similar results were found by Sánchez-Bravo et al. [67] with lactic acid bacteria in the pistachio brew. However, Cunha Júnior et al. [40] pointed out that Brazil nut, despite being a good matrix for *Lactobacillus casei*, did not prove viable after processing. One explanation for this event is that often the technological processes chosen for the production of the beverage can affect the viability of microorganisms. The authors themselves argued that a suggestion to increase the viability of probiotics was their microencapsulation or even a pre-acidification of the chestnut for the preparation of beverages.

Despite reports of nutritional loss and color change in beverages, which can often be accepted by the consumer, [37,40] fermentation still stands as a useful strategy within of tree-nut beverage production. The use of mixed culture fermentation has great potential to improve the nutritional quality and sensory profile of tree nuts beverages and the performance of crops is strongly dependent on species and strain. [74] The study by Mattison et al. [57] demonstrated that the fermentation of a yogurt based on cashew nut was able to reduce some allergenic factors of this nut during production, and that the final product had color, pH and viscosity similar to standard cow’s milk based yogurt.

Finally, with regard to microbiological aspects, the issue of contamination and microbiological safety of these beverages were also found during the survey and tree nut beverages after proper processing are considered safe. The study by Škubić et al. [72] points out that 2 out of 17 investigated beverages were contaminated with mycotoxins and the others had very low rates and were considered acceptable under local legislation. Sardão et al. [68] found that high-pressure treatment at 450 MPa for 5 min as well as heat treatment showed to be sufficient to inactivate Enterobacteriaceae, mesophiles, psychrophiles, and molds and yeasts over nine weeks of storage, such as heat treatment. Similar results were found by Valencia-Flores et al. [78] in the preparation of an almond drink during 20 days of storage. It is possible to state therefore that the combination of different preservation methods (pasteurization, fermentation and refrigeration) is sufficient to guarantee the microbiological stability of tree nut products without often resorting to the use of chemical preservatives. [40]

**Conclusion**

This review reinforces that although tree nut beverages can present a good nutritional and functional profile, they cannot be considered as a substitute, in their entirety, for cow’s milk, except in the case of allergies to this food. Even so, these products can have their profile improved through fortification, which is necessary due to the great variability in the nutritional composition of these nuts. In addition to the lack of certain nutrients, the flavor still seems to be a limiting factor in tree nut milks. In this sense, blends with other vegetables, fruits and nuts for fortification and flavoring seem to be positive for improving these aspects. Regarding processing, high pressure and temperature were positive in the preparation of nut tree drinks, with high pressure being more advantageous in some points; however, such associated methodologies seem to be more positive, although more studies are needed to stipulate this. The use of additives, despite showing rheological improvements in beverages, can be replaced by the addition of other vegetables, nuts, or even the use of high pressure to improve the properties in tree nut milks and drinks. Tree nut drinks are considered safe from toxicological and microbiological points of view. Tree nuts beverages are excellent matrices for adding probiotics, however their effect on the body still needs to be studied and in vivo analyzes need to be better clarified. Tree nuts beverages are very promising from a nutritional, industrial, environmental, and functional point of view for their growing consumer market when the correct techniques are used.

**Disclosure statement**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
Funding

This work was supported by the National Council for Scientific and Technological Development / Conselho Nacional de Desenvolvimento Científico e Tecnológico [CNpq 311108/2021-0]; Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado de Rio de Janeiro [E-26/211.379/2021]; Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro [E-26/202.710-2019]; Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro [E-26/201.302/2022]; Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro [E-26/202.187/2020].

ORCID

Victor Jonas da Rocha Esperança http://orcid.org/0000-0003-1890-3593
Caroline Corrêa de Souza Coelho http://orcid.org/0000-0002-1502-0843
Renata Tonon http://orcid.org/0000-0002-2891-2760
Renata Torrezan http://orcid.org/0000-0001-7272-3126
Otniel Freitas-Silva http://orcid.org/0000-0002-7658-8010

References

[1] Alasalvar, C.; Shahidi, F., Eds. Tree Nuts: Composition, Phytochemicals, and Health Effects; CRC Press: Boca Raton, 2008.
[2] Weinberger, T.; Sicherer, S. Current Perspectives on Tree Nut Allergy: A Review. JAA. 2018, 11, 41–51. DOI: 10.2147/JAA.S141636.
[3] Alasalvar, C.; Pelvan, E.; Topal, B. Effects of Roasting on Oil and Fatty Acid Composition of Turkish Hazelnut Varieties (Corylus Avellana L.). Int. J. Food Sci. Nutr. 2010, 61(6), 630–642. DOI: 10.3109/09637481003691820.
[4] Gama, T.; Wallace, H. M.; Trueman, S. J.; Hosseini-Bai, S. Quality and Shelf Life of Tree Nuts: A Review. Sci. Hortic. 2018, 242, 116–126. DOI: 10.1016/j.scienta.2018.07.036.
[5] McWilliam, V. L.; Perrett, K. P.; Dang, T.; Peters, R. I. Prevalence and Natural History of Tree Nut Allergy. Ann. Allergy Asthma Immunol. 2020, 124(5), 466–472. DOI: 10.1016/j.anai.2020.01.024.
[6] Jacobs, B. S.; DeJong, T. M. Tree Fruits and Nuts. In Encyclopedia of Agriculture and Food Systems, 2nd, Vol. 5, Van Allen, K. N.; San Diego, California,USA: Elsevier (Academic Press), 2014; pp 303–314.
[7] Robert, M.-C. Food Allergens: Seafood, Tree Nuts, Peanuts. In Encyclopedia of Food Chemistry, 1st, Vol. 1 Peter , Varelis, Laurence, Melton, Fereidoon, Shahidi; United States: Elsevier, 2019; pp 640–647.
[8] Wells, M. L. 1 - Agricultural Practices to Reduce Microbial Contamination of Nuts. In Improving the Safety and Quality of Nuts; Harris, L. J., Ed.; Cambridge, UK: Woodhead Publishing Series in Food Science, Technology and Nutrition: Woodhead Publishing, 2013; pp 3–21.
[9] Jamshidi, S.; Moradi, Y.; Nameni, G.; Mohsenpour, M. A.; Vafa, M. Effects of Cashew Nut Consumption on Body Composition and Glycemic Indices: A Meta-Analysis and Systematic Review of Randomized Controlled Trials. Diabetes & Metab Synth. Cln Res & Rev. 2021, 15, 605–613. DOI: 10.1016/j.jsxs.2021.02.038.
[10] Ribeiro, S. R.; Garcia, M. V.; Copetti, M. V.; Brackmann, A.; Both, V.; Wagner, R. Effect of Controlled Atmosphere, Vacuum Packaging and Different Temperatures on the Growth of Spoilage Fungi in Shelled Pecan Nuts during Storage. Food Control, 2012, 108173. DOI: 10.1016/j.foodcont.2021.108173.
[11] Choo, J. M.; Tran, C. D.; Luscombe-Marsh, N. D.; Stonehouse, W.; Bowen, J.; Johnson, N.; Thompson, C. H.; Watson, E.-J.; Brinkworth, G. D.; Rogers, G. B. Almond Consumption Affects Fecal Microbiota Composition, Stool PH, and Stool Moisture in Overweight and Obese Adults with Elevated Fasting Blood Glucose: A Randomized Controlled Trial. Nutr. Res. 2021, 85, 47–59. DOI: 10.1016/j.nutres.2020.11.005.
[12] Alcântara, D. B.; Dionisio, A. P.; Artur, A. G.; Silveira, B. K. S.; Lopes, A. F.; Guedes, J. A. C.; Luz, L. R.; Nascimento, R. F.; Lopes, G. S.; Hermsdorff, H. H. M., et al. Selenium in Brazil Nuts: An Overview of Agronomical Aspects, Recent Trends in Analytical Chemistry, and Health Outcomes. Food Chem. 2022, 372, 131207. DOI: 10.1016/j.foodchem.2021.131207.
[13] Zhao, L.; Zhang, P.; Zheng, Q.; Deka, A.; Choudhury, R.; Rastogi, S. Does a MediDiet with Additional Extra Virgin Olive Oil (EVOO) and Pistachios Reduce the Incidence of Gestational Diabetes? Endocr. Pract. 2021, DOI: 10.1016/j.eprac.2021.08.010.
[14] 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. Gastronomy Food Sci. 2021, 24, 100358. DOI: 10.1016/j.ijgfs.2021.100358.
[15] Rusu, M. E.; Simedrea, R.; Gheldiu, A.-M.; Mocan, A.; Vlase, L.; Popa, D.-S.; Ferreira, I. C. F. R. Benefits of Tree Nut Consumption on Aging and Age-Related Diseases: Mechanisms of Actions. Trends Food Sci. Technol. 2019, 88, 104–120. DOI: 10.1016/j.tifs.2019.03.006.
Compounds in Cashew Nuts (Anacardium Occidentale L.). *Talanta*. 2019, 205, 120100. DOI: 10.1016/j.talanta.2019.06.100.

[61] Morais, A. C. S.; Rodrigues, M. C. P. Optimization and Consumer Acceptability of Carob Powder as Cocoa Substitute in Lactose-Free Cashew Nut Almonds-Based Beverage. *Int. Food Res. J*. 2018, 25, 2268–2274.

[62] Pinto, D. D. S.; Silva, S. D. S.; Figueiredo, R. W. D.; Menezes, F. L. D.; Castro, J. S. D.; Pimenta, A. T. Á.; Santos, J. E. D. Á. D.; Nascimento, R. F. D.; Gaban, S. V. F. Production of Healthy Mixed Vegetable Beverage: Antioxidant Capacity, Physicochemical and Sensorial Properties. *Food Sci. Technol.* 2021, DOI: 10.1590/fst.28121.

[63] Pongthanakorn, S.; Veranitinin, R.; Mekswan, K. Clinical Outcome of Malva Nut Drink in Type 2 Diabetic Patients. *The FASEB Journal*. 2007, 21(5), A696–A696. DOI: 10.1096/fasebj.21.5.a696-d.

[64] Reboucas, M. C.; Rodrigues, M. D. C. P.; Afonso, M. R. A. In *Journal of Food Science*. 2014. Optimization of the Acceptance of Prebiotic Beverage Made from Cashew Nut Kernels and Passion Fruit Juice. Vol. Vol. 79, n. 7, pp S1393–S1398. DOI: 10.1111/1750-3841.12507.

[65] Reboucas, M. C.; Rodrigues, M. C. P.; Freitas, S. M. Utilization of Mathematical Models to Evaluate the Acceptance and Physicochemical Parameters for the Development of a Beverage Made from Cashew Nut. *Int. Food Res. J.* 2018, 25, 684–689.

[66] Reboucas, M. C.; Rodrigues, M. D. C. P.; Freitas, S. M. D. S. M. de How Label and Nutritional Claims Affect Consumers’ Acceptance, Buying Intention and Quality Perception toward a Beverage Made from Cashew Nut. *Nutr. Food Sci*. 2019, 49(6), 1243–1251. DOI: 10.1108/NFS-11-2018-0309.

[67] Sánchez-Bravo, P.; Noguera-Artiaga, L.; Carbonell-Barrachina, Á. A.; Sendra, E. In *Journal of Food Science*. 2020. Fermented beverage obtained from hydroSOSTainable pistachios; Vol. Vol. 85, n. 10, pp 3601–3610. DOI: 10.1111/1750-3841.15408.

[68] 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 an Quercus Acorn Beverage. *LWT*. 2021, 149, 111858. DOI: 10.1016/j.lwt.2021.11858.

[69] Scholz-Ahrens, K. E.; Ahrens, F.; Barth, C. A. Nutritional and Health Value of Milk and Milk Imitations. *Eur. J. Nutr*. 2020, 59(1), 19–34. DOI: 10.1007/s00394-019-01936-3.

[70] Silva, K.; Machado, A.; Cardoso, C.; Silva, F.; Freitas, F. Rheological Behavior of Plant-Based Beverages. *Food Sci. Technol*. 2019, 40(1), 258–266. DOI: 10.1590/fst.09219.

[71] Silva, J. G. S.; Rebello, A. P.; Caramés, E. T. D. S.; Greiner, R.; Pallone, J. A. L. In Vitro Digestion Effect on Mineral Bioaccessibility and Antioxidant Bioactive Compounds of Plant-Based Beverages. *Food Res. Int*. 2020, 130, 108993. DOI: 10.1016/j.foodres.2020.108993.

[72] Škrbić, B.; Živančev, J.; Godula, M. Multimycotoxin Analysis of Crude Extracts of Nuts with Ultra-High Performance Liquid Chromatography/Tandem Mass Spectrometry. *J. Food Compost. Anal*. 2014, 34(2), 171–177. DOI: 10.1016/j.jfca.2014.03.002.

[73] Srichamroen, A. Effect of Extracted Malva Nut Gum on Reducing High Glucose Levels by Caco-2 Cells. *Food Biosci*. 2018, 21, 107–116. DOI: 10.1016/j.fbio.2017.12.007.

[74] Tangya, M.; Muller, J.; Bolten, C. J.; Wittmann, C. Fermentation of Plant-Based Milk Alternatives for Improved Flavour and Nutritional Value. *Appl. Microbiol. Biotechnol*. 2019, 103(23–24), 9263–9275. DOI: 10.1007/s00253-019-10175-9.

[75] Thalukder, I.; Toröfðar, H.; Collard, M. Milk Alternatives. What Advice Should Dental Professionals Be Giving? Dental Update. 2021, 48, 359–366. doi:10.12968/denu.2021.48.5.359.

[76] Tiurikova, I.; Peregichnyi, M. Prospects of Using Walnut in Technologies of Drinks. *Acta Universitatis Cinabinesis, Ser E: Food Technol*. 2015, 192, 39–50. DOI:10.1515/aucft-2015-0013.

[77] Townsend, J. A.; Thompson, T.; Vaughan, S.; Wang, Y.; Qingzhaoy, Y.; Xiaoming, X.; Wen, Z. T.; Wang, Y.; Yu, Q.; Xu, X. Analysis of Fluoride Content in Alternative Milk Beverages. *J Clin Pediatr Dent*. 2019, 436, 388–392. DOI:10.17796/1053-4625-43.6.5.

[78] Valencia-Flores, D. C.; Hernández-Herrero, M.; Guamis, B.; Ferragut, V. In *Journal of Food Science*. 2013. Comparing the Effects of Ultra-High-Pressure Homogenization and Conventional Thermal Treatments on the Microbiological, Physical, and Chemical Quality of Almond Beverages. Vol. 78, pp E199–E205. DOI: 10.1111/1750-3841.12029.

[79] Zhang, Y. Y.; Hughes, J.; Grafenauer, S. G. M. The Emerging Role of Australian Plant-Based Milk Alternatives as A Cow’s Milk Substitute. *Nutrients*. 2020, 12. DOI: 10.3390/nu12051254.