PLANT BASED BEVERAGES: TYPES, PROCESS METHODS, NUTRITIONAL VALUE AND CONSUMER PERSPECTIVE

Abstract

Concerns about sustainability, animal welfare, environmental impact, personal health issues, and changes in eating habits have increased consumer demand for non-dairy plant-based beverages. Moreover, nondairy plant-based beverage consumption has increased due to the rise in the allergenicity of cow's milk, the prevalence of cardiovascular diseases, lactose intolerance, and the flexitarian choice of food. Nondairy Plant-based beverages are gaining popularity among consumers who are seeking alternative and environmentally sustainable options to traditional dairy drinks. The food industry is therefore developing a range of affordable, convenient, desirable, nutritional, and sustainable non-dairy plant-based beverages. They are good alternatives instead of dairy milk due to the existence of functional components such as bioactive with health-promoting functions. On the other hand, nutritional property and consumer acceptability in terms of taste, and flavor of non-dairy plant-based beverages is lower than cow's milk becoming a threat to its place in the food market. Therefore, this chapter provides an overview of the current knowledge on fundamental processing steps to convert plant material into plant-based beverages, types of plant-based beverages, and nutritional and sensory aspects of plant-based beverages.

Keywords: Plant-based beverages;nutritional value; milk alternatives; functional beverages

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I. INTRODUCTION

Healthy nutrition is the consumption of necessary and sufficient nutrients for growth, development, maintenance of life, and protection of health. Studies carried out in recent years show that healthy nutrition has an important role in reducing and preventing the risk of some diseases (Type-2 diabetes, obesity, cardiovascular disease, etc.) [1, 2, 3, 4, 5]. With modern life, the increase in consumers' demand for ready-to-eat foods has negatively affected their eating habits, and decreased physical activity has led to an increase in health problems such as Type-2 diabetes, digestive system ailments, obesity, and cardiovascular disease [6, 7].

The functional food sector is growing rapidly in parallel with the development of food and nutrition science, consumers' understanding of the diet/disease relationship, the increase in the elderly population, and treatment costs [2, 8, 9]. With the support of the development of the functional food sector by governments and the change in consumer awareness and production models, an increase in innovative food production is realized. One of the innovative food products is functional beverages, and the functional beverage market is growing by 10% every year worldwide [10]. Functional drinks can be classified as sports and performance drinks, energy drinks, milk-based drinks (with probiotic, protein, and mineral additives), and vegetable and fruit juices [11, 12]. In recent years, due to reasons such as cow's milk allergy, lactose intolerance, hypercholesterolemia prevalence, calorie concerns, and vegan/vegetarian diets preferred by consumers, plant-based beverages have started to be used in the production of functional beverages and are rapidly growing in the new food product development category [13].

In recent decades, the food industry has aimed to develop and produce alternative milk and dairy products with consumers' nutritional problems towards foods with improved functional properties because of the inadequacy of animal milk sources, together with their increasing awareness of demands and differences in dietary preferences (vegan/vegetarian diet, religious reasons) special diet), as in many foods obtained from plant sources [14]. Plant-based beverages are high in minerals and rich in health-promoting bioactive components such as vitamins, dietary fibers, and antioxidants. They are accepted as functional foods because they are similar to animal milk plant-based beverages or alternatives developed and marketed with the expression "milk". It takes place in the literature as a group under the name of milk drinks [15]. With the development of technology, plant-based milk can be produced from legumes such as soybean, lupine, lentil, chickpea, and pea; cereals like oat, rice, corn, or nut-based such as peanuts, coconuts, and hazelnuts. Plant-based milks have received more attention recently from consumers due to being lactose-free and cholesterol- free diets, vegetarians or people who prefer not to consume animal milk, deficiency of animal protein, and awareness of allergies to animal proteins. Although the most common plant- based milk is derived from soy, the demand for other plant-based milk like almond, rice, oat, and coconut milk, is also increasing [16]. Moreover, plant-based milk, whose usage areas are gradually expanding, such as yogurt, cheese, kefir, pudding, and

desserts have been started, and work continues in these areas. The worldwide plant-based food market is expected to grow by 12.5% annually from 2021 to 2028, reaching $20.5 billion [17]. To define this rise in the market, many factors can be considered reasons for the increase in the consumption of plant-based beverages. The rise in the cases of lactose intolerance, with a prevalence of nearly 57% all over the world and causing gastrointestinal symptoms, are the main reasons for the consumption of plant-based beverages [18]. However, there are many benefits of plant-based beverages, there is still concern about the nutritional value and consumer acceptance of plant-based beverages compared to dairy products. Therefore, the aim of the present study is to give an overview of the production methods, types, nutritional properties, and consumer preferences of plant-based beverages.

II. PROCESSING METHODS EMPLOYED TO MANUFACTURE PLANT-BASED BEVERAGES

The processing methods employed to manufacture plant-based beverages vary depending on the specific type of beverage being produced and the final products. However, common processing methods include soaking or germination, extraction, filtration, homogenization, heat treatment, fermentation, fortification, packaging, and quality control (Figure 1). Germination, or water soaking, is the first step in producing some plant-based milks like soybean, rice, hazelnut, almond, peanut, sesame seed, and tiger nut. This step can lead to the swelling and softening of nuts and cereals; therefore, the apparent amylose content can be decreased [19]. Moreover, when tiger nuts, soybeans, peanuts, and oats are soaked in water extraction yield of milk is raised. In addition, blanching can be applied to almonds, soybeans, peanuts, coconuts, rice, quinoa, and sesame which leading to many advantages, including the inactivation of enzymes like lipases, reduced microbial load, and removal of undesirable flavors and taste [20].

Extraction is extracting the desired components from the source material, such as fruits, vegetables, nuts, or grains. This can involve methods like juicing, grinding, wet milling, or blending to obtain the plant's liquid or pulp. For example, wet milling can be applied to cashews, tiger nuts, coconut, soy, cowpeas, almonds, peanuts, walnuts, and hazelnuts. This step includes the addition of water through the grinding of the raw materials. The type of feed rate and the grinding, pH value, and the amount of added water, and grinding temperature can affect on the nutritional, and physicochemical properties, and viscosity of plant-based milks. For example, when an increased amount of water can decrease the nutritional properties of plant-based milk [21]. The filtration step involves, after extraction, the liquid or pulp is typically strained to remove any solids, fibers, or unwanted particles. This process helps improve the texture and clarity of the beverage. Homogenization is often employed to create a more uniform texture and prevent separation in plant-based beverages. This process involves mechanically breaking down the fat molecules in the beverage to distribute them more evenly, resulting in smoother and more stable products

[20].

Many plant-based beverages undergo heat treatment to pasteurize or sterilization them, extending their shelf life and ensuring their safety. This can involve techniques like high-temperature short-time (HTST) pasteurization or ultra-high-temperature (UHT) processing. Glucosides and saponins are antinutrients due to their impacts on the digestion of proteins particularly soy proteins, which are resistant to digestion. Whereas different kinds of seeds, like oats and soybeans have different saponins, the applied heat treatment throughout the process during plant-based beverages may decrease the content of these kinds of compounds [22].

Consumers have nutritional concerns about the nutritional value of plant-based beverages compared to animal milk. Especially, plant-based beverages usually have deficiencies in important nutrients like high-quality proteins, vitamins, and minerals. The deficiencies of these nutrients can lead to some health problems especially the elderly and infants over time [23, 24]. Therefore, it would be advantageous to add some nutrients (vitamins and minerals) to plant-based beverages to avoid deficiencies. Plant-based beverages may also be fortified with various vitamins, minerals, or additives to enhance their nutritional value or improve their taste and texture. Common fortification ingredients include calcium, vitamin D, omega-3 fatty acids, and sweeteners. In addition, fortification of plant-based beverages with nutrients like polyphenols and carotenoids can lead to enhanced health benefits of these productions. Plant-based beverages are a suitable production vehicle for introducing essential nutraceuticals and nutrients into human diets. Plant-based beverages are colloidal dispersion that can be fortified with bioactive ingredients with different molecular polarities; hydrophobic, amphiphilic, and hyrophilic. Moreover, plant-based beverages can be designed to raise the bioavailability of the bioactive agents [25]. On the other hand, plant- based beverages have to be carefully designed so that the bioactive components continue to remain stable during the shelf life of production, should not affect negatively production quality, and are highly bioavailability after digestion. Once the beverage is processed and fortified, it is usually packaged in bottles, cartons, or aseptic containers to protect its quality and prolong its shelf life [26].

Packaging materials and methods vary, but they generally aim to maintain product integrity and preserve freshness. During the manufacturing process, quality control measures are implemented to ensure the safety, consistency, and compliance of the plant-based beverages. This can include regular product testing, monitoring of processing parameters, and adherence to regulatory standards [27].

Recently, eco-friendly techniques like ultrasound, high-pressure homogenization, fermentation, and the enzymatic process can reduce residue and enhance extraction yield. Moreover, many studies have already reported that these kinds of techniques improve the nutritional and sensorial properties of plant-based milk [28]. These processing methods play a crucial role in transforming raw plant materials into palatable and commercially viable

beverages, while also maintaining their nutritional value and ensuring consumer satisfaction and safety [29].

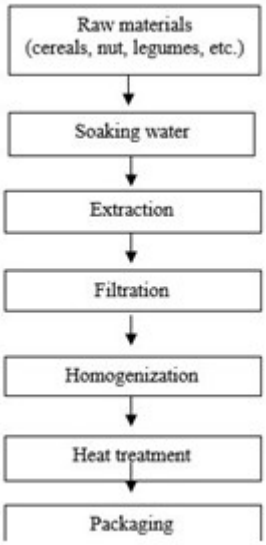

Figure 1: Manufacturing process of plant based beverages starting from raw materials.

III. APPLICATION OF INNOVATIVE TECHNOLOGIES FOR THE PROCESSING OF PLANT-BASED BEVERAGES

Thermal and non-thermal innovative technologies like microwave heating, ohmic heating, high-pressure homogenization, pulsed electric field, ultraviolet radiation, high-intensity ultrasound, and supercritical carbon dioxide have been researched as potential alternatives for the production of plant-based beverages. Productions of plant-based beverages with these innovative technologies may lead to enhancing shelf life, protecting nutritional value, and decreasing the loss of bioactive components.

1. **Thermal Innovative Technologies:** Microwave heating is an unconventional technique that is highly effective technique to decrease microbial load and increase the shelf life of production. The principle of this technique is based upon electromagnetic radiation, which has frequency from 103 to 104 MHz and that affects the dipole of the water molecules in production. The radiation enhances a rise in the intermolecular friction of the system because of the forces and repulsion of these dipoles of water molecules that delivering heat. Moreover, the rising in temperature is supported by ionic conduction due to the action of the electromagnetic area, which causes the displacement of the ions to areas that show opposite charges. Therefore, rising intermolecular collisions lead to disrupting hydrogen bonds in water [30, 31, 32]. Research has shown that the use of microwave techniques increases digestibility, eliminates antinutrional components, and

increases protein yield compared to conventional techniques [33, 34].

Ohmic heating is an innovative thermal technique that is applied in the processing of unpacked or packaged plant-based beverages. In this technique, an electrical current of 50 to 69 Hz is applied to the food matrix, which discharges thermal energy because of electrical resistance. The the molecule's agitation degree is increased by applying electrical energy to the system's resistance medium. Thus, heat release contributes to molecules' agitation [35, 36]. The rise in the heat of the medium, supported by uniform heating, which does not cause mechanical damage to production decreases the deteriorating and pathogenic microbial load from the rupture of its cell membranes. Moreover, ohmic heating is suitable for enzymatic inactivation with enzyme denaturation [37, 38]. Research has shown that using ohmic treatment on soy products leads to decreased in thiol loss and inactivation of antinutritional components such as chymotrypsin, and trypsin. Compared to conventional techniques, ohmic heat treatment is sustainable and low-cost. On the other hand, ohmic heating may promote overheating of production, causing protein denaturation and nutritional and sensory alterations of plant-based beverages [39].

2. **Non Thermal Innovative Technologies:** Ultra-high-pressure homogenization and high-pressure homogenization are alternative, nont-thermal innovative techniques for the production of plant-based beverages. This high pressure, which is between 200 and 600 MPa, and temperatures from 30 to 80 ℃ applied to food lead to the development of stability products by decreasing the particle size and promoting uniform size particles. Moreover, the microbial load can be decreased by this technique [40]. A study has shown that besides a reduction in particle size, there is not effect on the vitamins of the product. Furthermore, it is established that there is a decrease in protein antigens by applying ultra-high-pressure homogenization [41]. Another study has shown a remarkable reduction of particle size in the ultra-high pressure homogenization treated product samples compared to ultra-high treatment treated product samples. While protein aggregation was observed after 200 MPa, ultra-high-pressure homogenization at 300 MPa caused similar protein aggregation [42]. Furthermore, applying ultra-high pressure homogenization can contribute to physicochemical properties like color during storage, minimize the effects on nutritional properties, and improve sensory properties [43, 44].

The ultrasound technique is an alternative innovative non-thermal technique for plant-based beverages. This technique is equal to waves with a frequencies from 20 kHz to 100 MHz. Ultrasound techniques can be divided into two according to the frequency employed for food or beverages; high frequency (100kHZ to 1MHz) and low frequency (16 to 100 kHz) [45]. Productions of plant-based beverages by applying high-intensity ultrasound treatment results in the inactivation of pathogenic and endogenous enzymes. Moreover, the application of this treatment can allow rheological improvement [46]. A recent study has shown that the combination of thermosonication (heat) and ultrasound treatment results in better microbial stabilization of production [47].

Besides, the ultrasound technique is more energy efficient compared to conventional heat treatment because of the short processing time. Furthermore, this technique is easy to use, and providing volumetric heating led to minimal damage to the resistance of heat components of the productions [48].

The pulsed electric field technique has been particularly used for enzymatic inactivation and microbial stabilization of liquid productions involving plant-based beverages. This technique is applied at low temperatures between 30 to 40 ℃ less than 1 minute to in order to prevent thermal degradation of the food matrix. The treatment of this innovative non-thermal process provides a decrease in the microbial load of productions with induction [49, 50]. A study has shown that treatment with the pulsed electric flown technique (100-600 Hz, at 25 ℃) leads to a decrease in lipoxygenase activity in soy products. On the other hand, this treatment cannot inactive food spores, so other components, such as organic acids, which lead to a rise in thermal energy and water activity, should be added to pulsed electric field processing [51]. Besides the reduction in microbial load, treatment of this technique contributes to the maintenance of nutritional properties of production because of its non-thermal technique. Whereas the investment cost of the pulsed electric field technique is expensive, there are many advantages, such as high energy efficiency, shorter processing time, and protection of the vitamins, phenolic compounds, flavonoids and carotenoids [52, 53, 54].

Ultraviolet radiation technique attracts the attention of unconventional treatments for plan-based beverages. This technique relies on the germicidal impact provided by ultraviolet radiation. It provides mutation or disruption of the deoxyribonucleic acid of microorganisms, changing their morphological structure and reproduction function. Besides providing microbial inactivation, ultraviolet radiation treatment effect enzymes [55]. This technique provides photochemical changing in proteins, promoting enzymatic inactivation. Moreover, the ultraviolet radiation technique provides minimal altering to the nutritional and sensory properties of products. Once ultraviolet radiation is applied at low temperatures, this does not provide thermal aggregation of the thermosensitive components in food [56]. On the other hand, the application of this technique is only useful for liquid production. A higher dose of radiation can be applied for cloudy liquid production but it causes a decrease in the sensory properties of the production [55].

Supercritical technology is a non-thermal process that can apply to plant-based beverages to extend their shelf life. In this technology, food production is put into the reactor and saturated by the injection of carbon dioxide. Carbon dioxide is non-toxic, low cost and provides high extraction yields among supercritical fluids. Moreover, the critical condition of carbon dioxide moderate, which provides less damage to nutritional properties and a decrease in the process energy expenditure, compared to other fluids. Despite the effectiveness and low cost of carbon dioxide, the application of this technology on an industrial food scale is difficult because of the high investment costs [56, 57]. This technique decreases the load of endogenous enzymes and pathogenic

microorganisms in production, providing conservation. Supercritical carbon dioxide technique, in which the volume proportion of carbon dioxide (20 to 50%), the temperature at 35-55 ℃, and the impact of pressure (10-20 MPa), were evaluated on the physicochemical and rheological properties of beverages [58]. This application did not provide remarkable changes in the physicochemical properties of the beverages, whereas it changed the rheological properties of the coagulation of milk proteins by decreasing the pH during processing. Therefore, an additional homogenization process can be performed to improve kinetic stability [59].

IV. TYPES OF NON-DAIRY/ PLANT-BASED BEVERAGES

Various plant-based beverages are available on the market derived from legumes, cereals, seeds, nuts, or a mixture of plant sources as an alternative to dairy milk. Whereas there is no obvious classification and description of plant-based beverages in published studies in literature, commonly plant-based beverages can be divided into four broad categories based on raw material (Figure 2).

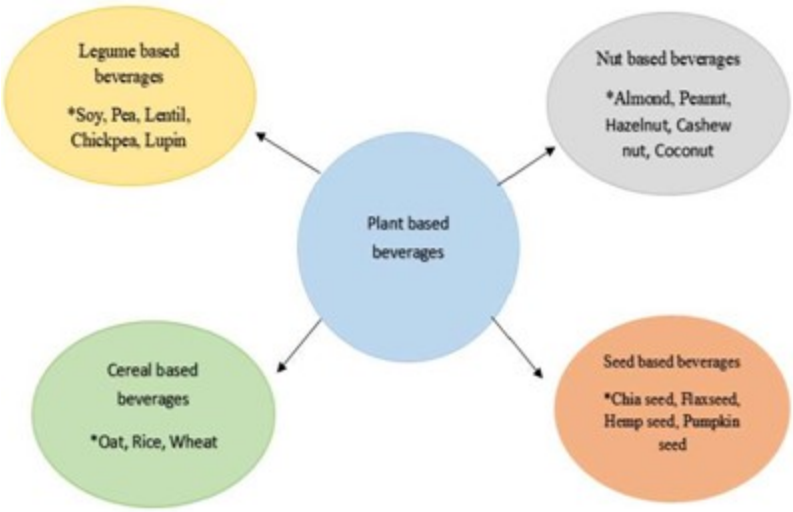

Figure 2: Categories of Plant Based Beverages.

1. **Legume-Based Beverages:** Legume-based beverages are drinks that are made in legumes, which are a type of plant from the Fabaceae family. Legumes are known for being a good source of protein, fiber, and various vitamins and minerals. Here are a few popular types of legume-based beverages:

    - **Soy milk**: Soy and soy products have received attention from vegetarians because of their high protein content and quality. Made from soaked and ground soybeans, soy milk is a popular dairy milk alternative. A study has reported that soymilk

contains 7/237 g/ml protein; the protein value of soymilk is nearly dairy milk protein [60]. Soy milk has a high amount of essential polyunsaturated and monosaturated fatty acids, which are related to cardiovascular health. Soy milk is a cheap, nutritional, and refreshing beverage with different functional properties that are beneficial for human health. For example, soy contains huge amounts of isoflavones, which have protective impacts against some diseases such as osteoporosis, cancer, and cardiovascular diseases. In addition, it contains minerals, fiber, unsaturated fatty acids, phytochemicals (sterols, phytic acid, and saponin), and vitamin B [61, 62]. Soy milk products are often fortified with vitamin D and calcium.

- **Pea milk**: This type of milk is made from yellow peas. Peas have high amount of protein (%18-20) and is often suitable for those with nut, soy, or dairy allergies. Moreover, pea proteins are high-quality and related to essential amino acids, and particularly high amounts of arginine and lysine. Pea proteins have beneficial functional properties like emulsifying power, gelation properties, foaming capacity, and water solubility [63, 64]. Pea proteins have higher digestibility and lower allergenic impacts, and lower antinutritional factors like phytate than soy proteins. Moreover, peas have great amounts of minerals and vitamins such as calcium, potassium, iron, folic acid, and vitamin B [65]. On the other hand, the unpleasant flavor of pea protein is the most limiting factor for using it in beverages [66].

- **Lentil milk**: Lentils are a nutritious legume and can be turned into a milk-like beverage. Lentil milk is known for its high fiber content and is often a good option for those following a vegan or plant-based diet. Moreover, lentil has vitamins B and folate, minerals and complex carbohydrates (dietary fiber, starch and oligosaccharides), and their fat content is less than %1 [67, 68]. The high protein level in lentil seeds makes them suitable for functional human foods. The studies have reported that firstly raw lentil seeds were cleaned and washed, then washed seeds were kept in water for 14 hours. The shells of the softened seeds are removed by hand, and they are mixed with water in a blender for 3 minutes and filtrated [69].

- **Chickpea milk**: Chickpea is another legume that can be transformed into milk. Chickpea milk is an excellent source of protein and can be used as a substitute for dairy milk in various recipes. Chickpeas have one of the highest nutritional compositions among legumes. It contains nearly 23 percentage protein, 64 percentage carbohydrate, 6 percentage fat and some minerals such as calcium, magnesium, phosphor, iron, and zinc [70]. The presence of undesirable components in chickpeas limits the wider use of chickpeas. However, undesirable factors can be reduced or eliminated with different cooking techniques. It has been reported that the starch content of different kinds of chickpeas varies from 41% to 50% [71]. The digestibility of chickpea carbohydrates is lower than that of other legumes. Chickpea milk has a darker and yellowish color than cow's milk. Chickpea are a food rich in folate content, so reduces the risk of colorectal cancer in humans [72].

- **Lupin milk**: These legume-based beverages provide alternatives for those who are lactose intolerant, have allergies to common milk sources, or are following a plant-based diet. They offer a range of nutritional benefits and can be consumed on their own or used in cooking and baking. Lupin has high amount of protein content (30%), fiber content (16%) and fat content (6%) [73]. Moreover, it has 18% and 33% of the recommended daily intake of riboflavin and thiamine, respectively. Lupin has a great amount of carotenoid, tocopherol, phytosterol, polyphenol, and peptides with anticancer, antioxidant, anti-inflammatory, and antimicrobial activities [74].

2. **Nut-Based Beverages:** Almond has a good amount of vitamin B complex comprising (B1, B2, B3, B5, B6), vitamin E, protein, dietary fiber, monosaturated fatty acids, phenolic compounds, and minerals (Mg, P, Ca and K). Moreover, compared to other plant-based milks, almond milk is a good source of vitamin E, which cannot be synthesized by the body and must be taken from diet [75]. Due to its high fiber, it is suitable for low sodium/high potassium diets. However, amandin which is a protein found in almonds can cause almond allergy [76]. Almond milk after soaking in plenty of water for a while, can be obtained by grinding, as well as directly grinding raw or roasted almonds into flour and diluting, and then using plant-based milk production methods. Compared to cow milk, the color of almond milk is darker and the protein content is lower. The prevalence of nut allergy and the high cost of almonds limit their use as a beverage [77].

   Peanut milk is made from ground peanuts and water, peanut milk is a rich and creamy alternative to cow's milk. It can be consumed on its own, used in cooking, or added to smoothies. Soaking raw peanuts is the first step in producing peanut milk followed by grinding with water after that filtration, and heat treatment. Processing conditions such as boiling or roasting have shown a rise in the amount of bioactive compounds. Peanuts are generally used for nuts and oil production. Peanut contains functional components such as proteins, fibers, minerals, vitamins, and antioxidants [21]. Recent studies have shown that peanut is a great source of Co-enzyme Q10 and involve all the essential amino acids with a high level of arginine. Phenolic compounds, which are flavonoid, resveratrol, phytosterols, and phenolic acid are found in peanuts and the study showed that they prohibit the absorption of cholesterols from food [78, 79, 80].

   One of the most notable plant-based milk available in the market is hazelnut milk. Hazelnut milk has 0.6-0.8 g of protein, 1.5-2.8 g of fat, and 6.5-8 g of carbohydrates in 100 mL on average. Hazelnut milk can be produced with reduced fat, added sugar, unsweetened, flavored, or on-demand fortified formulations [81]. Although hazelnut gives flavor to the products, the minerals in its composition fiber, tocopherols and phenolic compounds play an important role in nutrition and health support. Hazelnut is preferable for its sugar effect due to its low glycemic index. Due to the high mineral content (K, Ca, and P) in hazelnut milk, it suggests to pregnant women and against lactose an option for sensitive people to add to their diet instead of cow's milk [82].

Cashew nut milk is a plant-based milk alternative made from creamy and mild-flavored cashew nuts. Cashew nut milk is made by blending cashews with water and then straining the mixture to remove any solids. The resulting liquid is a creamy, nutty milk that can be used as a dairy-free alternative. Cashew nut milk is low in calories and contains a good amount of healthy fats, protein, and carbohydrates. It is also a source of vitamins and minerals such as vitamin E, calcium, magnesium, and potassium. However, it is important to note that store-bought versions may have added sugars, so it is advisable to check the ingredient list [83]. Cashew nut milk is a popular choice for individuals who are lactose intolerant, allergic to dairy or follow a vegan or plant-based diet. It can be used as a one-to-one replacement for dairy milk in various recipes, including smoothies, cereals, coffee, and baked goods. Cashew nut milk has a creamy and smooth texture, making it a great option for those who prefer a richer consistency in their beverages or recipes. It adds a subtle nutty flavor to dishes without overpowering the original taste [84]. Cashews used in cashew nut milk are a good source of healthy fats, including monounsaturated fats, which have been associated with lowering cholesterol levels, controlling coronary heart disease and diabetes, and maintaining healthy bones. They also provide dietary fiber, which can aid in digestion and promote satiety. Cashew nut milk is a dairy-free milk alternative with a creamy texture and subtle nutty flavor. It is a nutritious option for those following a vegan or plant-based diet and can be used in various recipes as a replacement for dairy milk [85].

Coconut milk is consumed mostly in Asian countries. It also is used as an ingredient, like a sweetener in different recipes. Coconut milk, extracted from the solid endosperm of mature coconuts, is a liquid and can be mixed with water to be consumed as a beverage. Coconut milk is rich in minerals, especially potassium, calcium, iron, zinc, and magnesium [86]. Moreover, coconut milk contains high levels of antioxidants like vitamin E. Coconut milk is high in saturated fat and healthier than other saturated fat products, and fat is easily metabolized by the body. The main saturated fat is lauric acid in coconut milk and it is also found in breast milk and promotes brain development and bone health, it strengthens our immune system, and maintains the flexibility of blood vessels [87].

3. **Cereal-Based Beverages:** Oats are good sources of dietary fiber such as β-glucan, phytochemicals, starch, and lipid components. Oats have received interest due to β-glucan, which is soluble fiber and can delay gastric empty time and cause gastrointestinal transit time that is related to blood glucose level [88]. However, the soluble fiber β-glucan tends to increase the viscosity of solutions. Oat milk has beneficial effects on human health like digestion system regulation, control of body weight, and type II diabetes. Although oat products have many health benefits, oat milk contains calcium, an essential nutrient for growth and development, which is poor; supplementation before consumption as a milk alternative to compensate for this deficiency needs to be done [89]. Oat milk is produced by UHT treatment and put into suitable packages in various sizes. Starch, which makes up the majority of oats (55-60%), has a gelatinization temperature range of

44.7-73.7 °C [90]. The existing high starch concentration of the oat drink in the preparation of a stable emulsion and the heat cause problems during processing. Starch, with applied heat, starts to gelatinize, and a high gel-like viscous structure formation which reduces the acceptability of oat milk is observed. the fluidity of oat milk during heat treatment is maintained in order to prevent starch hydrolysis [91].

Rice contains various proteins, carbohydrates, vitamins B1-B2, iron, phosphorus, calcium and small amounts of vitamins A and C. Among plant-based dairy products, after soy milk and almond milk, rice milk is the third most popular alternative dairy product and the most hypoallergenic of these products. Rice milk does not contain saturated fat or cholesterol. Compared to other plant-based milk, rice milk contains the least amount of fat [92]. Moreover, rice milk is rich in unsaturated fatty acids like oleic acid, riboflavin, niacin, thiamine, folate and β-carotene. Patients who have cardiovascular disease can consume rice milk because it is low in saturated fat and cholesterol. Although the protein ratio is quite low compared to other plant-based beverages, it is rich in complex carbohydrates and fiber content. Rice milk is rich in B vitamins, and some of the vitamins can be lost during rice milk processing [93]. Rice milk also contains low levels of calcium, so it needs to be fortified with calcium. Rice milk also supports the immune system, which helps prevent cancer. Moreover, it contains more magnesium and selenium than other plant-based milks. Consumption of rice milk can lead to the production of red blood cells and high iron and copper levels [94]. Rice milk is a rich source of carbohydrates, the sugar content is higher than cow's milk [95]. Therefore, people who have type II diabetes, should carefully consume rice milk.

Wheat milk, also known as kamut milk or spelled milk, is made by blending soaked wheat grains with water. It is similar in taste and consistency to rice milk but has a slightly nutty flavor [18].

Multigrain milk combines various grains like oats, rice, barley, and others, offering a unique flavor profile. It often provides a mix of nutrients from different grains [96, 97].

4. **Seed-Based Beverages:** Seed-based beverages are drinks that are made from seeds, either as whole seeds or as seed extract. These beverages are often known for their nutritional benefits and can be consumed for various health purposes. Sesame is one of the most important oil seed crops all over the world. Sesame has high-quality protein that has a good amino acid balance [96]. Its proteins are less soluble in water and susceptible to heat denaturation, which limits sesame use in the production of plant-based milk. For this reason, modification in the functionality of proteins are required before use in plant-based beverages. These modifications may be done with different types of processing methods, such as roasting, soaking, germination, and microwave heating [98, 99]. Chia seeds are soaked in water or other liquids to create a gel-like substance that can be enjoyed as a drink. It is often mixed with flavors such as fruit juices or milk alternatives to

enhance taste [100]. Flaxseeds can be ground into a powder and mixed with water or other liquids to make a drink. This beverage is known for its high omega-3 fatty acid content and is often consumed for its potential heart health benefits [101]. Hemp seeds can be blended with water or other liquids to create a creamy and nutty-flavored beverage. Hemp seed beverages are a good source of plant-based protein and healthy fats [100]. Pumpkin seeds can be blended with water or other liquids to create a nutritious and antioxidant-rich drink. This beverage is nutrient-dense and may provide various health benefits, including supporting prostate health [102]. These seed-based beverages can be enjoyed on their own or used as ingredients in smoothies, shakes, or even baked goods. They offer a convenient way to incorporate the nutritional benefits of seeds into your diet.

V. NUTRITIONAL PROPERTIES OF PLANT-BASED BEVERAGES

Plant-based beverages, also known as plant milk or alternative milk, are derived from a variety of plant sources and offer several nutritional properties. Some common plant-based beverages include almond milk, soy milk, oat milk, coconut milk, and rice milk. Here are some general nutritional properties of plant-based beverages:

1. **Low in Calories:** Plant-based beverages are generally lower in calories than cow's milk. However, the calorie content can vary depending on the type and brand of plant-based beverage [26].

2. **Low in Saturated Fat:** Plant-based beverages are typically low in saturated fat, unlike dairy milk, which contains significant amounts of it. This makes plant-based beverages a healthier option for individuals concerned about their saturated fat intake [102].

3. **Source of Vitamins and Minerals:** Plant-based beverages can provide valuable vitamins and minerals, depending on the plant source. For example, almond milk is a good source of vitamin E, calcium, and vitamin D (if fortified). Soy milk is naturally rich in calcium, vitamin D, and vitamin B12 [26, 102].

4. **Lactose-Free:** Plant-based beverages are naturally lactose-free, making them suitable for individuals who are lactose intolerant or have dairy allergies. This makes them a popular choice for those who cannot consume dairy products [102, 103].

5. **Cholesterol-Free:** Plant-based beverages are free of cholesterol, which is only found in animal-based products. This is beneficial for individuals looking to maintain heart health and lower their cholesterol levels [21, 26, 102, 103].

6. **Higher Fiber Content:** Some plant-based beverages, such as oat milk, contain a higher fiber content compared to cow's milk. Fiber supports digestive health and can help regulate blood sugar levels [104].

7. **Lower in Protein:** Most plant-based beverages are lower in protein compared to cow's milk. However, some brands enrich their products with additional protein from plant sources to help meet protein requirements [103, 105].

8. **Polyphenols:** These are a group of antioxidant compounds found in plants. They have been associated with numerous health benefits, including reducing the risk of chronic diseases such as heart disease, certain cancers, and neurodegenerative disorders. Polyphenols are particularly abundant in beverages made from berries, grapes, green tea, and cocoa [105].

9. **Carotenoids:** These are pigments responsible for the vibrant red, orange, and yellow colors in fruits and vegetables. Carotenoids have antioxidant properties and are known to support eye health, reduce the risk of certain cancers, and boost the immune system. Plant-based beverages rich in carotenoids include carrot juice, tomato juice, and orange juice [26].

10. **Phytoestrogens:** These are naturally occurring compounds that have a similar structure to estrogen and can mimic some of its effects in the body. Phytoestrogens are found in soy-based beverages, flaxseed milk, and certain herbal teas like red clover and black cohosh. They are believed to have potential benefits for managing menopausal symptoms, reducing the risk of certain cancers, and maintaining bone health [26].

11. **Alkaloids:** These are nitrogen-containing compounds with diverse biological activities. Some alkaloids found in plant-based beverages include caffeine in coffee and tea, theobromine in cocoa, and nicotine in tobacco. Alkaloids can have stimulating or sedative effects on the central nervous system and may also have medicinal properties [19].

12. **Omega-3 Fatty Acids:** These are essential fatty acids that play a crucial role in brain health, heart health, and reducing inflammation in the body. While they are more commonly found in fish and seafood, some plant-based beverages like flaxseed milk and hemp milk can be fortified with omega-3 fatty acids derived from plant sources such as algae [21].

13. **Variety of Flavors and Textures:** Plant-based beverages come in a range of flavors, including vanilla, chocolate, and original, which can be appealing to individuals seeking variety in their diet. Some also have a creamy texture that is similar to dairy milk.

14. **Fortified Options:** Many plant-based beverages are fortified with vitamins and minerals to make them nutritionally comparable to cow's milk. Common fortifications include calcium, vitamin D, and vitamin B12, which are often lacking in a vegan or vegetarian diet [106].

It's important to note that the nutritional properties of plant-based beverages can vary depending on the brand, processing methods, and added ingredients. Therefore, it is always recommended to check the nutrition labels and choose fortified varieties when possible.

VI. HEALTH EFFECTS OF PLANT-BASED BEVERAGES

Plant-based beverages can offer numerous health benefits due to their natural compounds and nutrients. Some of the health effects include:

1. **Nutrient-Rich:** Plant-based beverages such as almond milk, soy milk, and oat milk are often fortified with essential nutrients like calcium, vitamin D, and vitamin B12. These nutrients are beneficial for bone health, nutrient absorption, and energy production [107].

2. **Heart Health:** Many plant-based beverages, particularly those made from soy and almonds, are naturally low in saturated fats and cholesterol. They can contribute to lower blood cholesterol levels and decrease the risk of heart disease [16, 108].

3. **Digestive Health:** Some plant-based beverages contain high amounts of dietary fiber, which aids digestion and supports a healthy gut. For example, oat milk is known for its beta-glucan fiber, which can help regulate bowel movements and promote a healthy digestive system [106, 109].

4. **Antioxidants:** Certain plant-based beverages, such as green tea or matcha tea, are rich in antioxidants. These compounds help to fight free radicals and reduce oxidative stress, potentially reducing the risk of chronic diseases like cardiovascular issues, cancer, and neurodegenerative diseases [110, 111].

5. **Reduced Lactose Intolerance Symptoms:** For individuals with lactose intolerance, plant-based beverages like almond milk or rice milk provide a dairy-free alternative. They do not contain lactose, a sugar found in dairy products that many people have difficulty digesting. 80% of the total protein in cow's milk is casein, and the rest is whey protein. Individuals with cow's milk allergies are sensitive to various milk proteins such as casein, beta-lactoglobulin, alpha-lactalbumin, bovine serum albumin, bovine immunoglobulin, and bovine lactoferrin, which are the main milk allergens [112]. Cow's milk allergy is a very common type of allergy among infants and children, and large-scale studies show that allergies that starts in infancy increase by 35% at advancing ages (5-6 years), and this rate increases to 80% when they reach the age of 16. has been emphasized in various studies [113, 114, 115].

6. **Reduced Allergies or Intolerances:** Plant-based beverages are suitable for individuals with allergies to common allergens like dairy, soy, or nuts. Beverages made from less common ingredients like hemp, flaxseed, or rice can provide a safe and nutrient-dense option [16, 116].

7. **Weight Management:** Plant-based beverages, especially those made from non-starchy vegetables or nuts, can be lower in calories compared to traditional dairy products. They can be used as a healthier substitute for high-calorie beverages, aiding in weight management or weight-loss efforts. The majority (97-98%) of cow's milk fat consists of milk fat, which is triglyceride, and the remainder contains free fatty acids, mono-diglycerides, phospholipids and cholesterol. A cohort study of 80,000 people, it was stated that there is a significant relationship between the consumption of fatty cow's milk and the risk of coronary heart disease [117]. This situation is associated with an increase in the risk of coronary heart disease as a result of the intense consumption of dairy products, which in increasing serum cholesterol [118, 119]. In many studies investigating the effects of dairy products on health, it is emphasized that high-fat milk consumption has a negative effect on health [84, 85]. This situation has caused consumers to negatively affect their consumption habits due to the high amount of saturated fat and cholesterol in cow's milk [120].

It's important to note that the health effects may vary depending on the specific ingredients, processing techniques, and added sugars in plant-based beverages. Reading labels and choosing products without excessive additives or added sugars is recommended for optimal health benefits.

VII. CONSUMER PERSPECTIVE

Consumer acceptability of plant-based milk has been growing steadily in recent years. The increasing popularity of vegetarian, vegan, and flexitarian diets, along with concerns about animal welfare, environmental sustainability, and health, have contributed to the rise in demand for plant-based milk. One of the main reasons for consumer acceptability is the taste and texture of plant-based milk. In the past, plant-based milk alternatives often had a different taste and texture compared to cow's milk, which deterred some consumers. However, advancements in manufacturing processes and ingredient formulation have allowed for a significant improvement in the taste and mouthfeel of plant-based milk [121, 122]. Many brands now offer a wide range of options that closely mimic the taste and texture of cow's milk, such as almond milk, soy milk, oat milk, and coconut milk. Another factor driving consumer acceptability is the increased availability and variety of plant-based milk products [123, 124, 125]. Grocery stores now have dedicated sections for plant-based milk, with a broad assortment of flavors, types, and brands. This accessibility has allowed consumers to experiment with different options and find the ones that best suit their preferences.

Health considerations also play a significant role in consumer acceptability. Plant-based beverages are often lower in calories, saturated fat, and cholesterol compared to cow's milk. They are also suitable for individuals who are lactose intolerant or have milk allergies [126]. Furthermore, many plant-based milk products are fortified with vitamins and minerals, making them a nutritionally balanced option. Environmental sustainability is another factor that drives consumer acceptance of plant-based milk. Cow's milk production is

resource- intensive and contributes to greenhouse gas emissions. Plant-based milk, on the other hand, requires less water, land, and energy to produce, making it a more environmentally friendly choice. For individuals concerned about the environmental impact of their food choices, plant-based milk provides a viable alternative [122, 125]. In conclusion, consumer acceptability of plant-based milk has increased due to factors such as taste improvements, increased availability, health considerations, and environmental sustainability. As more consumers embrace plant-based diets and look for alternatives to animal-based products, the popularity of plant-based milk is likely to continue to grow.

VIII. ENVIRONMENTAL IMPACTS AND SUSTAINABILITY

A rising number of consumers, particularly the younger generation, are concerned about their food choices, both healthy and sustainable, eco-friendly. The research on the sustainability of plant-based beverages has not been widely reported, and its effect on consumer beverages has not been studied. The sustainability problems of plant-based beverages vary among the category of plant-based beverages, and the problems differ in degree of magnitude [126, 127, 128, 129]. A study has reported that the production of plant-based beverages like rice, soy, almond, and oat milk, is related to nearly 22-38% of the greenhouse gas emissions related to dairy products. Moreover, the use of water during the production of plant-based beverages is much less than for dairy products [130, 131]. While almond and rice productions have very high water usage, oat and soy productions have quite low water usage. For one liter of rice milk production, nearly 270 liters of water is needed; and 370 liters of water are required for the production of one liter of almond milk. However, rice and almond beverages require less water compared to the production of cow's milk. Moreover, cow's milk needs more land for its production than any other plant-based beverages [131].

Almond farming has a disadvantageous impact on bees due to pollination on almond trees [126]. However, compared to almond, hazelnuts are pollinated by wind instead of honeybees and grow in humid regions where water is required much less [127]. Rice not only requires more water but also produces more greenhouse gas emissions than other crops that are used for plant-based beverages [128, 131]. Oat and soy milk are considered more eco- friendly beverages compared to other plant-based beverages because of less water needed and land usage [131]. As mentioned before, beverages produced from rice, almonds, and soybeans have remarkably lower land usage, water usage, and greenhouse gas emissions than dairy products. There is still a gap about the effects of plant-based beverages on the environment; therefore, more studies are needed for all kinds of plant-based beverages to present their eco-friendliness and impacts on the environment. Sustainability problems are very complicated and there may be huge variability in the environmental effect of not only types of plant-based beverages but also in the same category, subject to the sustainability of farming techniques used for growing crops.

IX. ADVANTAGES AND LIMITATIONS

Plant-based beverages are often lower in calories, fat, and sugar compared to dairy-based beverages. They are also cholesterol-free and may contribute to a reduced risk of heart disease, obesity, and certain cancers [28, 79, 122, 124]. Plant-based beverages come in a wide range of options, such as almond milk, coconut milk, oat milk, hemp milk, and more. This diversity allows individuals to choose the flavor and consistency that suit their taste preferences and dietary needs. Many plant-based beverages, such as almond milk and soy milk, are fortified with essential nutrients like vitamins A, D, and B12, calcium, and protein. This makes them a good alternative for those who have dietary restrictions or are following a vegan or vegetarian diet [16, 17]. Some people have difficulty digesting dairy products due to lactose intolerance or milk allergies. Plant-based beverages provide a lactose-free and dairy- free alternative that is easier on the digestive system [106, 109]. Producing plant-based beverages requires fewer natural resources like water, land, and energy compared to dairy production. It can have a lower carbon footprint and contribute to reducing greenhouse gas emissions. Plant-based beverages require significantly less water and land compared to animal agriculture. Choosing plant-based options can help conserve freshwater resources and reduce deforestation associated with animal farming. Plant-based beverages are a compassionate choice for those concerned about animal welfare. By choosing plant alternatives, individuals can avoid supporting the factory farming industry, which often involves the mistreatment of animals [124]. Plant-based beverages are free from common allergens like lactose and casein, making them suitable for people with allergies, intolerances, or sensitivities to these substances [16, 17]. Plant-based beverages can be used in various culinary applications, just like dairy milk. They can be consumed as a drink, used in cooking and baking, added to smoothies and shakes, or used as a substitute for coffee, tea, and other beverages. With the increasing popularity of plant-based diets, plant-based beverages are becoming more widely available in grocery stores, cafes, and restaurants. This accessibility makes it easier for individuals to incorporate them into their lifestyles.

Plant-based milk substitutes may not be nutritionally identical to dairy milk. They might lack certain essential nutrients, such as calcium, vitamin D, and vitamin B12, which are naturally found in cow's milk [16, 28]. Although some brands fortify their plant-based milk with these nutrients, there can still be variations in the amount and bioavailability of nutrients. Moreover, plant-based milk usually has a lower protein content compared to cow's milk. This can be a limitation for individuals who rely on milk as a significant source of protein in their diet, such as athletes or those following a high-protein diet. Plant-based milk may not have the same creamy or rich taste as dairy milk. Some people find the flavor of plant-based milk substitutes less appealing, especially when used in beverages or cooking and baking [127]. In addition, depending on the region, the accessibility and affordability of plant-based milk substitutes may be limited. In some areas, the variety of options might be restricted, making it difficult for individuals with specific dietary requirements to find suitable options. Furthermore, while plant-based milk can be a suitable alternative for individuals with lactose intolerance or milk allergies, some people may have

allergies or intolerances to specific plant-based milk, such as soy, almonds, or nuts. This can restrict the options available to those individuals [128]. While plant-based milk substitutes are generally considered more environmentally friendly than dairy milk, some alternatives, such as almond milk, require large amounts of water and energy to produce. Additionally, the cultivation of certain crops for plant-based milk production can contribute to deforestation and other negative environmental impacts [129]. Plant-based milk substitutes often require processing to mimic the taste and texture of dairy milk, which can involve the addition of stabilizers, emulsifiers, and sweeteners. While these additives are generally recognized as safe, some individuals may prefer to avoid them for personal or health reasons. It is important to note that while plant-based milk substitutes have limitations, they can still be a suitable option for those who choose to avoid dairy milk due to personal preferences, dietary restrictions, or ethical reasons.

X. SUMMARY AND FUTURE DIRECTIONS

The tendency towards plant-based foods, which is a new approach, has increased in recent years due to reasons such as the increase in the number of individuals with lactose intolerance and cardiovascular disease, the spread of a vegan lifestyle, the replacement of animal-derived protein with plant-derived proteins, which may contribute to sustainability, and climate change continuing to increase day by day. The increasing world population combined with limited resources (arable land and freshwater) has created the need for alternative protein sources to meet global protein requirements. Plant food sources are accepted as inexpensive sources of both macro and micronutrients to manage malnutrition and improve the nutritional status of individuals in underdeveloped and developing countries. However, plant-based beverages generally have a lower protein content than dairy beverages. In the plant-based beverage industry, there is a need for nutraceutical-enriched beverages that are balanced in terms of nutritional content and can replace meals (protein quality and quantity). There is a need for research on preparing more nutritious and delicious personalized products for the functional plant-based beverage industry. In future studies, it is recommended to fortify the plant-based beverage in terms of protein, calcium, and vitamins. In addition, the sensory properties of the developed plant-based beverages can be investigated by applying different flavoring agents. It is recommended to determine consumer preferences based on the glycemic index, shelf life, and demographic characteristics of the product and to conduct in vivo studies.

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