REVIEW PAPER

Plant-Based Milk as Functional Delivery Systems for Bioactive Compounds: Nutritional and Technological Perspectives

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ABSTRACT

Owing to their increasing popularity, plant-based diets are driving the demand for plant-based milk (PBM) as a healthier alternative to traditional dairy milk. This review provides a synthesis of multiple aspects of PBM, including its sources, nutritional composition, sensory properties, health benefits, and potential limitations. We reviewed the macro and micronutrient compositions of various types of plant-based milk, including soy, almond, oat, rice, coconut, cashew, and hemp milk. While free from lactose and cholesterol and containing numerous bioactive compounds, PBM also lacks sufficient amounts of protein, calcium, and vitamin B12. However, the review also covers altering the nutritional and functional properties of PBM through fortification or novel processing methods (i.e., fermentation and enzymatic treatment). This review further considers the sensory properties of various PBM varieties in terms of consumer acceptance and formulation. The environmental sustainability of producing PBM, which has lower greenhouse gas emissions and less land and water usage than dairy milk, was also addressed. Nevertheless, challenges such as nutrient bioavailability, anti-nutritional factors, and regulatory aspects remain key areas that need to be addressed in the future. This research highlights the importance of extending processing technology and ingredient improvement innovations to close the nutritional difference between plant-based milk and dairy milk to achieve greater consumer acceptability and health gains.

Keywords: Plant-based milk, Vegan milk alternatives, Dairy-free beverages, nutritional composition

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INTRODUCTION

Although personal milk is primarily consumed by children, the effect of plant-based plant consumption on the growth and validity of children's nutrition is unclear. Nutritional recommendations contribute to plant-based foods; however, excellent health and nutritional organizations such as the American Academy of Pediatrics recommend milk over plant-based milk for children aged 1-5 years (Lott et al., 2019). For children who do not consume cow's milk (for example, from allergies or a vegan diet), fortified soy milk is considered to be a suitable alternative, as it is the most nutritious, similar to the cow (Comeford et al., 2021) in the field of other vegetables, such as almonds and coconut milk, which can be enriched with important nutrients, such as calcium and vitamin D, but contain less energy and protein compared to cow and soy milk (Vanga et al., 2018). In addition, many of these children had an allergy to cow's milk or atopic diseases, which may have contributed to the observed results and not to the use of milk-based milk (Jhamnani et al., 2018). Plant-based milk (PBM), such as oats, almonds, rice, and soymilk, has become a popular alternative to dairy milk because of its environmental sustainability and health benefits (Comeford et al., 2021). Compared with dairy milk production, PBM production emits only one-third of greenhouse gases and requires far less land (Singhal et al., 2017). Unlike milk, PBM (vegetable milk) does not contain lactose or milk protein. This is the best choice for those who have allergies to milk or lactose intolerance (Vitoria 2017), especially in African, American, and Asian ethnic groups, where lactose intolerance indicators range from 75% to 95% (Keller et al., 2012). Additionally, it does not contain cholesterol, is rich in vitamins and minerals, is useful for lactose intolerance, and can help reduce cholesterol levels, diabetes, and other diseases (Morency et al., 2017). Recently, there has been a rapid increase in the consumption of PBM in the global food sector, accompanied by significant consumer awareness of health issues and the environment (Morence et al., 2017). PBM's global market share reportedly rose from less than 10% in 2015 to >13% in 2018. China is among the largest markets for milk alternatives (Jhamnani et al., 2018). Most vegan plant-based milk is formulated by diluting oilseeds, grains, legumes, and/or seeds with water (Rincon et al., 2020). The common methods for producing milk typically include soaking, grinding, separating, hydrolyzing, whitening, heat processing, homogenizing, and formulation (McClements et al., 2019). The major benefit of consuming plant-based milk instead of dairy is the absence of lactose and cholesterol. It is rich in minerals, phenolic compounds, monolayers, and polyunsaturated fatty acids (Sethi et al., 2016). However, on many occasions, plant-based milk has comparatively low concentrations of proteins, vitamin D, and certain minerals compared to dairy milk (Chalupa-Krebzdak et al., 2018; Rincon et al., 2020). In addition, a number of studies have shown that the sensory appeal and broad acceptance of plant-based mills are relatively low

(Mäkinen et al., 2015; Pineli et al., 2015; Rincon et al., 2020).

There is a need for additional research dedicated to the production of plant-based milk with optimal chemical, physical, and sensory properties. The nutritional properties of vegan milk are influenced by its ingredients and processing methods. In general, plant-based milk products are produced with only one ingredient, which leads to lower quantities of protein, calcium, and iron than dairy milk. Research has indicated that the protein content of market plant-based milk products is generally less than 0.5%, with the exception of soymilk. Additionally, a mixture of raw materials can be used to reduce the disadvantages of plant-based milk (Jeske et al. 2017). The increasing popularity of plant-based products is related to personal health and care. Food-based dietary guidelines (FBDG) are correlated with eating patterns associated with a lower risk of non-communicable diseases (NCDs), and emphasize the inclusion of meat and dairy to illustrate the relevance of plants and plant foods (James et al. 2022). A sustainable and healthy diet that supports human health and well-being is environmentally available and culturally accepted while having the least impact on the environment. It supports planetary health and biodiversity (Lartey 2019).

The distinction between plant-based vegan milk is characterized by innovative formulations and better nutritional profiles to suit different consumer preferences. In fact, recent studies have demonstrated that various plant sources, as well as processing methods, can increase its nutritional value and sensory attributes to create a new milk alternative that surpasses traditional soymilk in terms of amino acid profiles and protein digestibility (Wang et al., 2024). The innovation of this study is its exploration of plant-based vegan milk substitutes and their nutritional aspects, sensory characteristics, health benefits, and health risks.

This study reviews many types of plant-based milk, including soy, almond, oat, rice, coconut, cashew, and hemp milk, by assessing their macronutrient and micronutrient compositions compared to traditional dairy milk. The goal of this review was to provide a thorough review of the state of milk alternatives derived from plants to examine nutritional adequacy, sensory characteristics, and potential health outcomes. It considers recent advances in processing and formulation options to improve the nutritional and functional characteristics of plant-based vegan milk, particularly as it generally addresses topics related to nutrients, bioavailability, anti-nutrients, and regulations that are worth considering in future research and development.

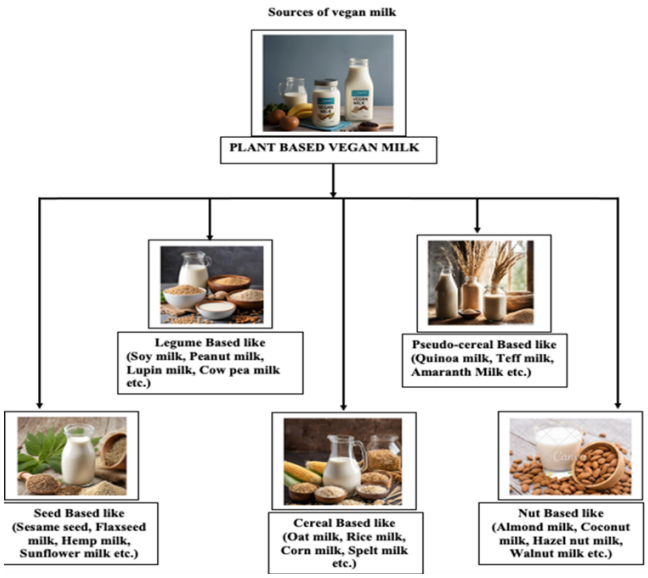

Figure 1: Different sources of plant-based milk

2. Types of plant-based milk

Different types of plant-based milk are commonly used as an alternative source with some health benefits and different functional and nutritional properties and, various case studies that are being studied are, as follows:

2.1 Soy Milk

Soy milk is a traditional plant milk that is slow to be produced. As is the case with all plant milks, soymilk provides nutrition very similar (though not exactly the same) as milk itself. It is relatively low in calories and provides a high amount of protein and calcium. Soy milk is an excellent replacement for milk in most recipes and is very stable at high temperatures. It can also be used as a milk substitute for tea and coffee, and can be foamed (Haas et al., 2019). Soybeans are an excellent source of protein and are a great substitute for milk-based beverages. Soy is a plant protein that provides all 10 essential amino acids, and its cost is comparable to that of other plant-based milks. An approximately 8-ounce serving of sugar-free soy can provide 105 calories, 6 g protein, and 4 g fat. The superfood is a fantastic choice that is nutrient dense, and an excellent source of vitamins, particularly vitamin B12 and vitamin D, and minerals like calcium, phosphorus. Soy milk is easy to find and is a relatively cheap alternative to milk (Sethi et al., 2016). According to Eslami and Shidfar (2018), in patients with non-alcoholic fatty liver disease (NAFLD), soy milk consumption could have significant benefits, resulting in a significant decrease in serum alanine aminotransferase and the sensitivity of C-reactive protein (CRP), but neither benefit was elaborated. Durazzo et al. (2015) stated that, in the same way, soy milk may have a wide range of health benefits, including potential cancer risk reduction and blood pressure treatment. Its nutritional profile and antioxidant properties make soymilk a valuable alternative to milk,

especially for those with lactose intolerance. In addition, Taha et al. (2024) noted that soymilk contains high levels of proteins, including proteins with some essential amino acids (threonine, leucine, and lysine), which are more than 90% of the recommended amino acid indicators. In addition, it is high in unsaturated fatty acids, which comprise a portion of the fats in milk-olive and linoleic acids. Another aspect of soy milk is the high humidity content (88.5%), which can promote greater dilution of nutrient concentrations compared to soy flour. Lastly, Sato et al. (2023) addressed a study of sumo wrestlers and reported that soymilk maintained the body composition of the wrestlers without differences in muscle mass, thus suggesting that soymilk works towards a balanced diet (Sato et al., 2023).

2.2 Almond Milk

Almond poplar vegan milk has a relatively low protein content and contains many vitamins and other nutrients, such as vitamin E. Almond milk is rich in a variety of antioxidants that can protect against many diseases, including cancer and heart disease. Homemade almond milk is a good source of calcium (Haas et al., 2019). It contains omega-3 fatty acids, which are important for heart health, antioxidants, and vitamin E. It is naturally low in sugar and is available in a variety of flavors. Almond milk is a delicious drink that is easily consumed. Alternatively, you can drink smoothie, cocktail, tea, or coffee. Cook it in sweet and flavorful dishes and add it to the oatmeal. Nevertheless, almond milk is too sweet for piquant dishes and, as a rule, is used to make desserts and smoothies for people (Haas et al., 2019). Almond milk has a nutty flavor and also contains magnesium, selenium, and vitamin E. Glass almond milk (8 oz) generally contains 40 calories, 3.58 grams of fat, and 1.51 grams of protein (Miller 2006). Almond milk is more readily available than other types of vegetable milks. Therefore, almond milk is one of the best plant-based plants (Sethi et al., 2016). Redan et al. (2024) reported that it is possible to fortify almonds with trace elements such as vitamins A, D2, riboflavin, calcium, and zinc, and most of the nutrients remain stable with short-term treatment (HTST) at high temperatures. However, after treatment at 116 °C, the thiamal content decreased by 17.9%, whereas that of vitamin B3 increased by 35.2%. Samarasinghe et al. (2023) reported that local almonds (Terminalia Catappa L.) can be used to produce milk-based milk with higher raw protein, fat, and fiber contents than milk. Sensory grade showed that milk from well-broken almonds was preferred, except for the scent. This study suggests blending at different maturity stages to enhance the nutritional quality. Yillamaz-Esran and Topcuoglu (2021) reviewed a study that investigated the effects of almond milk addition to probiotic yogurt on color, texture, and sensory attributes. Researchers have found that almond milk significantly influences yogurt color and texture parameters, and storage time also plays a role. Sensory evaluation revealed statistically significant differences between the samples. This study concludes that almond milk can be used as a new and functional ingredient in the development of dairy products and innovations. Ellis and Lieb (2015) conducted an interesting causal study that reported three children with hematuria, dysuria, or kidney stones associated with excessive consumption of almond milk. The study found that almond dairy products are particularly rich in oxalate. All urinary problems were resolved after stopping the use of almond milk, which emphasizes the importance of moderation in consumption.

2.3 Cashew Milk

Cashew milk is a new product recently added to plant milk. Filled with a heavy heart and unsaturated fat. This is useful for people with diabetes who have healthy lifestyles. Complete cashew milk accounts for 20% of our daily magnesium needs and is also a rich source of monounsaturated fatty acids and potassium. This is important for improving heart health. Vegan milk has a creamy consistency and can be used to produce tea, coffee, kitchens, and for cooking. Currently, they are available in most grocery stores. Cabjaine milk has a sweet hazelnut taste (Haas et al., 2019). Shori et al., 2022, studied that various studies have shown that cashew milk can effectively maintain the yogurt enzymes in a probiotic strain such as Lactobacillus rhamnosus and Lactobacillus casei. These strains can significantly increase the number of bacteria and antioxidants in dairy products during storage. This indicates that cashew milk is a functional ingredient in yogurt. Olayinka et al. (2018) found that cashew yogurt exhibited a favorable nutritional profile with a higher protein content than commercially available yogurt. Sensory grades indicate that cashew yogurt is usually well-recognized, indicating its potential as a dairy alternative. Uslu & Özcan (2017) reviewed nut-based studies and showed that cashew milk contains a significant amount of healthy fats, especially monounsaturated fatty acids such as polyunsaturated fatty acids such as oleic acid (59.59-61.82%) and linoleic acid. This information was then included in the analysis. (18.20–26.28%). Mattison et al. (2020) focused on cashew yogurt (keshegurto) containing sufficient probiotic bacteria (more than 10 million colony-forming units per milliliter) but showed that the enzyme process has a different effect on nut allergens.

2.4 Oat Milk

Oat milk has a soft, slightly sweet taste and higher fiber content than other milks. Fiber is important in a balanced diet for healthy digestion. Suitable for stimulating sweet recipes prepared from cereals, smoothies, creams, and transport soups (Haas et al., 2019). Oat flake milk is rich in soluble fiber and β-glucan, but has fewer proteins, vitamins, and minerals than milk. As a rule, the glass of oatmeal contains 130 calories, 2 g fat, and 4 g protein. Its creamy consistency helps enhance milk-based items such as pastries, soups, and lattes. Plant-based milk contains more carbon than other milk options, making it a good option for energy drinks. Oat milk contains fiber and natural proteins and can be fortified with vitamins A, B2, B12, and D, calcium, and phosphorus minerals. It did not contain lactose, nuts, or flooring. Therefore, it is a suitable option for the treatment of allergens. This is a safe option for those who

suffer from celiac disease if performed with certified gluten-free oats. Wei et al. (2024) investigated high-energy fluid microfluidization (HEFM), which improves the physical stability and nutritional quality of whole oat milk, boosts protein content, and diminishes starch content. McCarron et al. (2024) pointed out that oat milk contains many advantageous compounds, such as β-glucan, avenanthramide, and abenacoside, which provide health benefits. Cui et al. (2023) focused on various case studies examining oat milk production, its characteristics, and its potential as a dairy substitute. Research has focused on enhancing its stability, flavor, and nutritional value. Zhou et al. (2023) conducted studies comparing oat milk derived from different cultivars and showed that the Chinese Bayou 01 (ZBY01) cultivar is particularly suitable for processing, providing greater stability and sensory suitability. The oat milk contained approximately 1% protein, 9.84 mg/mL of β-glucan and 70.96 mg GAE/100 g DW of polyphenols.

2.5 Hemp Milk

Hemp milk is derived from the seeds of hemp plants. This plant-based milk is high in protein and has a rich, creamy texture. In addition, hemp milk accounts for approximately 50% of α-linolenic acid (α-LA) in a regular diet. α-LA is an omega-3 fatty acid that is necessary for healthy heart and brain function. Owing to its strong flavor, it is typically used more often in spicy dishes (Haas et al., 2019). Hemp seeds are a good source of magnesium, folate, phosphorus, and potassium and are typically combined with calcium, phosphorus, and vitamins A, B12, and D. Plant milk (Haas et al., 2019). Karabulut et al. (2024) reported that GABA-concentrated hemp milk was developed through solid conferencing and germination, resulting in a significant increase in GABA content (up to 102.45 mg/100 mL) and improved antioxidant activity compared with untreated milk. Gram and Mortas (2023) evaluated the effects of ultrasound and high-pressure homogenization on the physicochemical properties of hemp milk, optimizing production conditions for better quality. Wang et al. (2018) found that hemp milk produced using these process frameworks had a significantly higher GABA content than untreated milk. Furthermore, biologically active milk samples show improved stability, reduced particle sedimentation, and increased antioxidant activity. Another study investigated the use of high-pressure homogenization (HPH) in conjunction with PH shift treatment to obtain non-thermal, physical, and oxidative hemp milk. Nissen et al. (2020) reported that hemp milk prepared using this combined treatment exhibited significant stability, with negligible phase separation during storage at 4°C for 3 days. In addition, hydroperoxides can resist oxidation. Contradictory attentional concentrations for improving the stability of hemp milk have been studied to investigate hemp-seed drinks.

2.6 Rice Milk

When water is mixed with sweeteners, rice is converted into boiled rice milk. Because of its sweet taste, it is great for desserts, and a thin texture can be used in soup or light sauces. However, certain textures may require thickeners such as cornstarch, flour, or xanthan gum (Haas et al., 2019). Rice milk is an easy alternative for patients with allergies to nuts, seeds, soy, and dairy products. It is also available in a wide range of grocery establishments. Rice milk has an edge in terms of carbohydrate content compared to other plant milks. In addition, it is inexpensive, and its quality may be improved through fortification with calcium, vitamin B12, vitamin D, and vitamin A (Chalupa-Krebzdak 2018). Probiotic cultures can be used to improve the probiotic properties of rice milk while still preserving healthy bacterial counts and existing in storage (Mr et al., 2021). Shiriaev et al. (2024) focused on the effects of different bacterial strains on the fermentation of rice milk, which was geared towards improving the nutritional value while providing other antioxidant benefits. The highest increase in components providing antioxidant capacity was observed in Bifidobacterium strains. Goonathilaka et al. (2023) examined the fabrication of value-added rice milk products utilizing two varieties of rice and samba with local spices of cloves, ginger, and garlic. The final product had very high antioxidant capacity, with beneficial antioxidants and antimicrobial components. This study further demonstrates the possibility of fortifying the food profile of rice milk products by including more nutrient-dense/beneficial forms of rice milk products. Moore et al. (2023) recently inspected a research study that evaluated the nutritional content of several substitutes for plant-based milk, including rice milk or cow's milk ingredients. The outcomes indicated, like the majority of alternatives to plant-based alternatives, rice milk has great protein, lipid, amino acid, and mineral content compared to cow and goat milk. These aspects provide a few more considerations of the functional issues of rice milk.

2.7 Coconut Milk

Coconut milk is available in two forms: can or drink. Banks generally offer what is used in the kitchens. It adds a delicious taste to any dish in which it is used and works well when used in cooking. Coconut milk is ideal for various types of recipes such as desserts, soups, stews, sauces, smoothies, puddings, and ice cream. Coconut milk, which is used for drinking, is thin and can be used in tea, coffee, and cereals (Haas et al., 2019). Coconut milk is rich in minerals, such as manganese, magnesium, potassium, copper, and selenium, and contains triglycerides in the middle chain. The fiber content was higher than that of other plant-based milks. Large varieties of coconut milk are available for various culinary purposes such as drinks, sauces, cooking, and cooking. Sitorus and Lapcharoensuk (2024) reported that a study using an in-depth learning algorithm to detect falsification in coconut milk revealed the effectiveness of NIR spectroscopy, achieving a high precision in the determination of adulteration. Chen et al. (2024) studied the fat content in coconut milk and showed that optimal fat levels (approximately 10%) increase stability and digestibility, making it suitable for various applications. Tuminah and Sihombing (2015) reviewed a study indicating that adults consuming coconut milk more than three times a

week had a 1.3-fold increased risk of vascular disease compared to those consuming it less frequently (OR=1.33; 95% CI: 1.11-1.60; p=0.002). Jimenez et al. (2022) focused on a case study of a 5-month-old infant who developed hepatic steatosis due to the exclusive consumption of homemade coconut milk formula, which resolved upon discontinuation. This highlights the potential dangers of coconut milk in children's diets, especially when it is used as a major nutritional source.

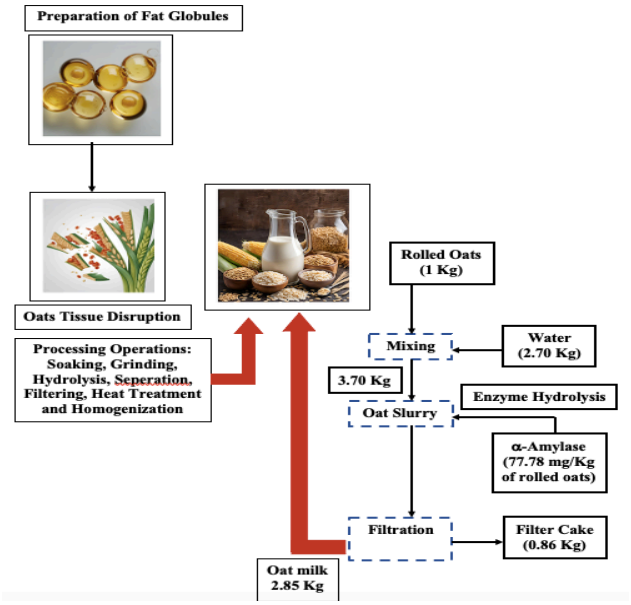

Figure 2: Development of Process Technology for oat milk

3. Plant milk vs. milk

Traditional food studies have shown that adults consume approximately 300 g dairy products per day. The most popular option is milk; however, condensed milk may be replaced by evaporated milk from dairy products. Condensed and steamed milk is a dairy product produced after the amount of water is reduced (Miller 2006). Plant milk is a plant juice similar to cow/animal milk, and refers to industrial drinks rather than milk made up of vegetable extracts for taste and aroma. Doshi plants are vegan drinks with a creamy sensation in the mouth, which can be replaced with milk. Plant liquids are generally packed in containers similar to those used for milk but cannot be marked "milk." HR milk has been a popular drink for a long time and is also a fragrant element of sweet and salty products, such as curry prepared from coconut milk. Plant milk is also used to prepare ice cream, cream for plants, vegan cheese, yogurt, and many other products (McClements, 2019). Plant-based milk produced from soybeans, oats, and almonds is a good substitute for milk of animal origin. Because plant milk has a gritty texture, some companies add sugar and thickeners to make their products smoother and tastier. Therefore, consumers should check their nutritional labels in detail before purchasing them to avoid the addition of sugar. Common plant milks include almond, coconut, rice, and soymilk, whereas other plant milks include hemp and oat milk. (Sethi et al., 2016). Vegetable milk is often produced from the extracts of beginners. Vegetable docks have a lower density of nutrients than milk, which strengthens the exact levels of trace elements, usually calcium and vitamins (A&D), during production (Vanga et al., 2018). The different plant-based milk types are shown in Figure 3.

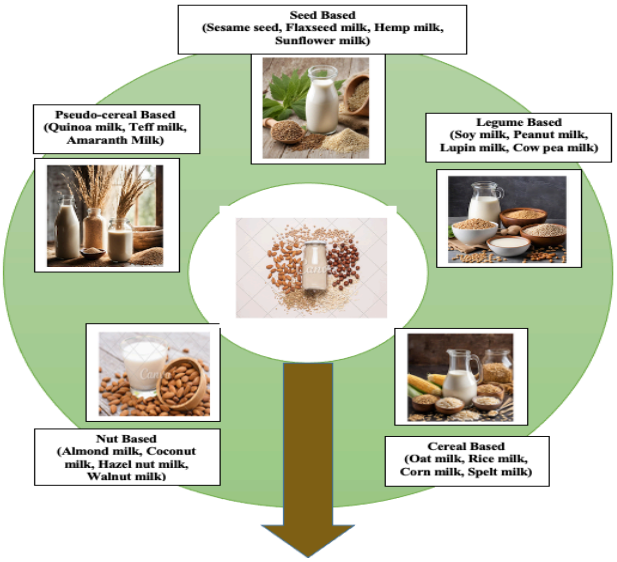

Fig. 3. Different types of plant-based milk from various plant sources.

4. Nutritional profile of plant-based milk alternatives

The source material and processing techniques have a substantial impact on the nutritional composition of plant-based milk substitutes. Due to ethical, environmental, and health concerns, these substitutes are becoming increasingly popular. Compared to conventional dairy milk, they provide nutritional issues, even though they have certain benefits. Adzuki and mung bean milk contain 2.19% and 1.63% protein, respectively, which are lower than dairy milk in most plant-based milks (Ong et al., 2024). The exception is soymilk, which has protein levels that are on par with those of dairy. Coconut-based milk has a higher saturated fat content than most plant-based milk (Moshtaghian et al., 2024). The amount of carbohydrates also varies, with some substitutes including extra sugars. Although many plant-based milks are fortified with vitamins D, B2, and B12, they frequently lack calcium and iodine compared to dairy products (Moshtaghian et al., 2024). The nutritional profiles and vitamin contents of various plant-based milks are shown in Table 1.

Table 1: Comparative Nutritional Profile of Plant-Based Milk Alternatives

Type of Milk	Calories (kcal)	Protein (g)	Fat (g)	Carbohydrates (g)	Calcium (mg)	Vitamins (e.g., B12)	References
Soy Milk	95±15.6	8.71±1.6	2.4 (1.3-3.8)	4.4 (0.4-8.9)	108 (10-160)	Vitamins B1, B2, B6 & B9.	Silva *et al.*, (2024)
Almond Milk	36.43±6.90	1.67±1.63	1.9 (1.1-3.8)	2.5 (0-6.5)	101 (7-128)	Vitamins E & K (in trace amounts).	Vashisht *et al.*, (2024)
Oat Milk	55 (48–71)	1.1 (0.2–2.3)	2.1 (1-3.1)	7.8 (6-11.7)	99 (3-120)	Vitamins B1, B5, B6 & B9.	Daszkiewicz *et al.*, (2024)
Coconut Milk	48.75±7.5	0	3.3 (1.4-7.9)	3.1 (0.3-7.8)	93 (16-120)	Vitamins D, B12 & A.	Lu *et al.*, (2024)
Rice Milk	133±13.04	0.85±0.75	1.1 (0.5-1.3)	10.4 (9.5-12)	108 (80-120)	Vitamins B1, B3, B12, and D.	Najman *et al.*, (2024)
Hemp Milk	36 (26–45)	0.4 (0.3–0.5)	2.7 (2.7-2.7)	2.4 (0.1-4.6)	ND	Vitamins B5, B7, D2, B12, etc.	Rawal *et al.*, (2023)
Cashew Milk	24 (18-29)	0.5 (0.4-0.5)	1.5 (1.4-1.5)	2.2 (0.8-3.6)	120 (120-120)	Vitamins E, B12, A & D, and D2.	Yaman (2024)

There are visible differences in macronutrient composition, health benefits, and customer perceptions between plant-based milk alternatives when comparing their nutritional profiles. Knowing how nutritious these substitutes are compared to regular dairy is crucial for making crucial dietary decisions as their requirements increase. Mung bean milk is an example of a plant-based milk that typically has lower quantities of protein (ABM: 2.19%, MBM: 1.63%) and carbohydrates than soymilk (Ong et al., 2024). According to Ong et al. (2024), these substitutes have iron content comparable to that of soymilk and bovine milk, and magnesium levels comparable to those of bovine milk. Monounsaturated and polyunsaturated fatty acid ratios are higher in plant-based cheeses than in dairy cheeses (Jaeger et al., 2024). With the greater post-meal blood glucose levels after ingesting almond beverages compared to cow's milk, studies suggest that plant-based substitutes may not be able to match the metabolic effects of dairy (Silva et al., 2024). The comparative nutritional profiles of various plant-based milk samples are presented in Table 2.

Table 2: Comparative Nutritional Profile of Plant-Based Milk Alternatives

Types of Milk	Calories (g)	Protein (g)	Fat (g)	Carbs (g)	Calcium (mg)	Key Nutrients	Components	SFA	MUFA	PUFA	References
Soy Milk	80-90	7-8	4-5	4-5	300-400	Isoflavones	Soy milk	0.4	0.4	1.3	Harmer *et al.*, (2024)
Almond Milk	30-50	1-2	2-3	1-2	300-400	Vit-E	Almond Milk	0.4	N/A	N/A	Antunes *et al.*, (2024)
Oat Milk	120-130	2-4	5-7	16-20	300-400	Beta-Glucans	Oat Milk	0.1	N/A	N/A	Pointke *et al.*, (2022)
Coconut Milk	45-60	< 1	4-5	1-2	300-400	MCTs	Coconut Milk	0.9	N/A	N/A	Bharti *et al.*, (2021)
Rice Milk	110-120	< 1	2-3	22-25	300-400	Simple sugar	Rice Milk	0.2	0.2	0.7	Molina (2023)

5. Fatty acid profile of plant based vegan milk

The fatty acid profiles of many alternatives to plant milk (PBMA) are remarkably different from those of cow milk, showing their unique nutritional properties. This review highlights the main differences in the composition of fatty acids among popular PBMAs, including almonds, oats, cashews, soy, hemp, coconut, and rice. The fatty acid composition was as follows: soymilk is rich in polyunsaturated fatty acids (AGPI), particularly linoleic acid (C18:2 Ω-6), contributing to an omega-6 / omega-3 ratio of 3.43 (Martínez-Padilla et al., 2020). Almond milk is dominated by Monounsaturated fatty acids (MUFAs), particularly oleic acid (C18:1 Ω-9), contain important triacylglycerol species such as TG 18:1_18:1_18:1 (Blasi et al., 2023). Oat milk is similar to almond milk and contains high levels of oleic acid, showing good protein digestibility of proteins (Martínez Padilla et al., 2020). Coconut milk is characterized by a high proportion of saturated fatty acids (SFAs), particularly lauric acid (C12:0), which is very different from other PBMAs (Annet et al., 2024). Rice milk has a lower fat content, with a profile that varies depending on treatment and strength (Pérez-Rodriguez et al., 2023). Cashew milk is rich in MUFA and PUFA, which are beneficial to cardiovascular health. Cashew milk has lower SFA levels than milk. This is beneficial for reducing the risk of cardiovascular disease (Hesus et al., 2023). The presence of these unsaturated fats is consistent with the overall trend towards replacing plant-based milk, which usually has a higher unsaturated fat content than milk. This low SFA content is consistent with other nuts based on nuts that usually have a healthier profile of fatty acids than animal milk (Antunes et al., 2024). Approximately 87% of the total fatty acids in hemp seeds are unsaturated, with linoleic acid being the most common (Gimeno-Martínezetal., 2023). GLA is present in significant amounts and contributes to the anti-inflammatory properties of hemp milk (Moon et al., 2005). Hemp milk has low saturated fatty acid content, making it healthy for the heart (Jyothi, 2024). The fatty acid profiles of the various types of vegan milk are shown in table 3.

Table 3. Fatty Acid Profile of Plant-Based Vegan Milk

Type of Milk	Total Fats (g)	Saturated Fats (g)	Monounsaturated Fats (g)	Polyunsaturated Fats (g)	Omega-3 (g)	Omega-6 (g)	References
Soy Milk	1.8	0.3	0.4	1.1	0.15	0.95	(Taha *et al.*, 2024)
Almond Milk	1.2	0.1	0.9	0.2	0.02	0.18	(Banjanin *et al.*, 2021)
Oat Milk	1.3	0.2	0.5	0.6	0.5	0.55	Klajn *et al.*, 2021)
Coconut Milk	2.1	1.9	0.1	0.1	0.0	0.1	Patil *et al.*, 2018)
Rice Milk	1.0	0.1	0.3	0.6	0.0	0.6	(Romulo *et al.*, 2022)
Cashew Milk	1.6	0.3	1.0	0.3	0.03	0.27	(Tamuno *et al.*, 2019)
Hemp Milk	3.0	0.3	0.4	2.3	0.6	1.7	(Amato *et al.*, 2024)

6. Health benefits and concerns of plant-based milk

The health benefits and concerns of plant-based milk alternatives (PBMAs) are multifaceted, reflecting their growing popularity and the need for careful consideration of

their nutritional profiles. Although PBMAs offer several advantages, including suitability for lactose-intolerant individuals and promotion of a sustainable lifestyle, they also present nutritional challenges that warrant attention. PBMA is often fortified with vitamins and minerals, which makes it beneficial for individuals with dietary restrictions. For example, fermented plant-based drinks can increase nutrient bioavailability and digestibility, and increase vitamin and amino acid levels (Hidalgo-Fuentes et al., 2024). Recent studies have shown that it improves physiological functions that play an important role in these plant drinks in improving or treating the immune system, has potential antibacterial effects, and reduces the risk of low bone mass. It also helps reduce the risk of cardiovascular and gastrointestinal diseases. Very high levels of antioxidants and free radicals. Milk and plant extracts were obtained from plants (Akin and Ozkan 2017). Oat flour has anticarcinogenic effects that decrease LDL cholesterol levels. It is rich in fiber, antioxidants, and polyphenols (Sharma et al., 2019). Soy milk is a source of essential fatty acids and is considered a healthy heart that reduces vascular disease. Treatment properties and protective roles in several age disorders (Nawaz et al., 2022). Almond milk, which is rich in monocellularized fatty acids, helps cope with weight and lower LDL cholesterol levels (Vanga et al., 2020).

In children and adolescents, milk plays an important role as a source of proteins, origin, fatty acids, and key growth factors for growth and development. Studies have systematically demonstrated the advantages of milk and other animal products in terms of growth, cognitive indicators, and the nutritional status of children. Consumption of dairy products is largely associated with growth and an increase in the weight and density of bone minerals in children (Hess et al., 2019). In contrast, a substantially non-existent healthy plant diet of animal origin is associated with a reduced risk of diabetes, cardiovascular disease, healthy cancer, and weight in adults. New research into the role of microorganisms can shed light on plant dietary possibilities for the modulation of inflammation markers and their effects on bone remodeling, thereby protecting long-term bone health. You can do it. Certain cake plants contain biologically active compounds, for example, owing to their abundance and phytosterols in soy or anti-screen factors, such as oatmeal phitat (Han et al., 2021). It has been concluded that a plant diet is not harmful to adult bone health when the contributions of calcium and vitamin D are appropriate (HSU 2020). The key health benefits of the various types of plant-based milk are shown in Table 4.

Table 4. Health benefits and concerns of plant-based milk

Type of Milk	Key Health Benefits	Allergens	Anti-Nutritional Factors	Digestibility	Unique Concerns	Recommended For
Soy Milk	The ability to contact estrogen receptors and develop properties such as estrogen. Eliminate the symptoms of menopause. It reduces the risk of breast, prostate, and colon cancer. Protective effects against osteoporosis and cardiovascular disease. Cholesterol-lowering properties. It functions as an anti-inflammatory agent.	Glycinin, B-conglycinin, profilin, P34 (Gly m Bd 30K), and Kunitz trypsin inhibitor, which can trigger IgE-mediated allergic reactions.	Trypsin inhibitors, phytic acid, and saponins	It is moderately digestible due to protein content. (mainly glycinin & β-conglycinin).	A unique concern with soy milk is a potential risk from soy allergies, which affect a significant portion of the population. Phytoestrogens (isoflavones) present in soy can mimic estrogen in the body, raising concerns about hormonal balance, particularly for individuals with hormone-sensitive conditions.	Soy milk is recommended for the individuals who are looking for a high-protein alternative to dairy milk, especially for vegetarians and vegans. It is a good source of essential fatty acids and vitamins like B12.
Almond Milk	Reduces plasma cholesterol. Reduces the oxidation lipid. Improves gastrointestinal health. Prebiotic properties.	almond proteins (amandin), including prunin and albumin.	Oxalates and phytates	It is relatively easy to digest due to its low protein content but is high in fiber and fat.	The primary concern with almond milk is its high oxalate content, which can contribute to kidney stone formation in susceptible individuals. Almonds also have a high water footprint, raising environmental concerns about the large amount of water required to produce almonds.	Almond milk is recommended for the individuals seeking a low-calorie, low-sugar dairy alternative with mild flavors. It is a good choice for the people looking to avoid saturated fats and those who are lactose intolerant.
Oat Milk	Delay the time of gastric emptying. Reduction of postprandial glycemic response because of the increasing of gastrointestinal transit. Lower total cholesterol and LDL levels. Control your weight and blood pressure.	oat seed storage proteins like avenins, which are prolamins that can trigger allergic reactions in sensitive individuals.	Avenins and phytic acid	Oat milk is digestible, and its primary fiber (beta-glucan) promotes gut health and a cholesterol reduction.	Oat milk is a concern for individuals with a gluten sensitivity or celiac disease, as oats can be cross-contaminated with gluten unless they are specifically labeled as gluten-free.	Oat milk is recommended for the people that are gluten sensitive (if gluten-free certified) or lactose intolerant. It is rich in fiber, particularly beta-glucan, which supports heart health.
Coconut Milk	Promotes brain development. Maintains the elasticity of the blood vessels. It boosts the immune system. Reduces LDL cholesterol and increases HDL cholesterol.	Cocosin (a globulin).	Tannins	It is highly digestible due to its composition of medium-chain triglycerides.	A unique concern with coconut milk is its high saturated fat content, which can raise the cholesterol level if consumed in an excessive quantity.	Coconut milk is recommended for the individuals that are seeking a creamy, rich alternative to dairy milk in cooking and baking. Its high saturated fat content may not be suitable for individuals on a low-

						fat diet, but it can be a healthy option for those who are looking for medium-chain triglycerides (MCTs) for energy.
Rice Milk	Lower cholesterol levels. Reduces high blood pressure. Antidiabetic properties. Anti-inflammatory properties. Antioxidant activity.	globulins, albumins, and prolamins.	Phytic acid	Rice milk is easily digestible with its carbohydrate content that is readily broken down and absorbed.	Rice milk is low in protein and can be very high in sugar, particularly in commercially available sweetened varieties. The high glycemic index of rice milk raises concerns about its impact on blood sugar levels, making it less suitable for individuals with diabetes or who manage their blood levels.	Rice milk is recommended for people with soy or nut allergies, as it is free from both. It is a hypoallergenic option for individuals with sensitivities.
Hemp Milk	Hemp milk supports heart health, bone health, and digestive health while boosting immunity and providing essential nutrients.	Edestin.	Fiber inhibitors and trypsin inhibitors	Highly digestible, as it contains omega-3 and omega-6 fatty acids and protein that can be easily absorbed by the body.	Hemp milk is often considered expensive and may not be widely available in some of the regions. While it is a good source of healthy fats, the concern with hemp milk is its distinct flavor, which may not be palatable to all the consumers.	Hemp milk is recommended for the people who are seeking a well-balanced source of healthy fats, including omega-3 and omega-6 fatty acids. It is a good option for an individual following a plant-based diet, especially for its protein content.
Cashew Milk	Lowers LDL cholesterol by inhibiting cholesterol biosynthesis.	albumins, vicilins, and legumins.	Phytic acid, which may reduce nutrient absorption and digestion.	Relatively digestible with a smooth texture due to its fat content.	A primary concern with cashew milk is the high fat content, which may not be suitable for those that are on low-fat diets. Cashew milk can also contribute to allergic reactions in sensitive individuals.	Cashew milk is recommended for individuals that are looking for a creamy, low-calorie dairy alternative that works well in smoothies, coffee, and baking.

7. Plant-based milk alternatives

Plant-based milk alternatives include colloidal suspensions and emulsions consisting of dissolved plant materials (Deep et al., 2017). PBMA is prepared by restoring (breaking down) extracted raw materials in water with subsequent homogenization; however, the composition and size of the particles are not homogeneous (Zannini et al., 2016). The size distribution of particles in aquatic extracts ranges from 5 to 20 µm, simulating cow's milk in terms of appearance and consistency (Sethi et al., 2016). Particle size and final product stability depend on the nature of the raw material, disintegration method, heat or homogenization treatment, and storage conditions (Silva et al., 2020). The treatment of plant-based milk alternatives includes various methods to improve nutritional and sensory properties to solve stability issues. Recent studies have underscored the importance of choosing raw materials, processing techniques, and product characteristics. The following sections elaborate on these factors.

7.1 Innovative therapeutic methods

Methods such as fermentation and germination have been tested to improve the nutritional profile and digestibility of plant-based milk. Research on novel treatment methods, including fermentation and germination of vegan milk, has yielded promising results regarding functional qualities and nutritional improvements. These methods address the common vitamin deficiencies associated with vegan diets and improve the quality of plant-based milk alternatives. Fermentation combined with germination considerably enhances the amount of essential amino acids; for instance, one study found that lysine and histidine levels were increased by 4.8 and 3.8 times after treatment (Luo et al., 2024). The presence of probiotics in milk increases during fermentation, as is the case with L. fermentum, which increases the amount of probiotics and organic acids in milk and enhances gut health (Luo et al., 2024). Co-fermentation with solid-state fermentation and germination increased the GABA concentration of hemp milk to 102.45 mg/100 mL, which was higher than that in samples without treatment (Karabulut et al., 2024). These methods also minimize sedimentation, reduce droplet size, improve milk and beverage stability, and make it more favorable to the consumer (Karabulut et al., 2024).

7.2 Emulsion stability

The incorporation of vegetable proteins and fiber-based ingredients, such as soy protein isolate and β-glucan, is extremely important with respect to droplet size, viscosity, and instability of emulsions, all of which play key roles in defining quality (Kramm et al., 2024). The first agents affecting stability in the emulsion of plant-based milk are processing methods involving the choice of stirrer and the addition of stabilizers and plant proteins. Recent studies have illustrated the functionality of various proteins and emulsifiers in enhancing the stability of plant-based milk emulsions, which contributes to increased product quality and market acceptability. Soy and pea protein isolates (SPI and PPI respectively) induced the highest emulsifying functionality; the droplet diameters of PPI and SPI emulsions were 57.9 µm and 60.0 µm respectively. These proteins can be used in formulations for plant-derived milk gels as they also enhance the antioxidant properties of gels (Galani et al., 2023). This natural emulsifier has been shown to increase the viscosity and flexibility of cream-type emulsions, which enhances their stability and may be useful in vegan milk applications (Szymanska et al., 2024).

7.3 Enhanced nutritional profile

Plant-based milk is abundant in proteins, fibers, and bioactive compounds, which adds to its appeal as a substitute for dairy products. Red kidney milk has high protein content and favorable rheological characteristics (Tang et al., 2023). Significant advancements have been made in plant-based alternatives, particularly through the use of legumes and seeds, as a result of investigations focusing on the high nutritional value of vegan milk. The

nutritional profile of dairy products is improved by various processing techniques, making these products suitable alternatives to conventional dairy products. As shown in figure 4, through germination, vegan milk made from mung beans reached a protein level of 4.39%, which is equivalent to that of animal milk (Joshi et al., 2022). Milks made from legumes, such as black bean milk, are rich in unsaturated fats and vital amino acids, which help maintain a healthy diet (Santiworakun et al., 2024). Hemp seed milk offers a complete nutritional profile because it is rich in vitamins (such as vitamin E) and minerals (such as calcium and iron) (Beşir et al., 2022). Wang et al. (2024) reported that certain compounds, such as those combining germinated soybeans and fermented cereals, showed improved protein digestibility compared to traditional options. Although plant leaks offer health benefits, their sensory properties often lag behind those of cow's milk, which affects consumer preferences. Innovations in transformation aim to improve taste and flavor profiles (Karayigit and Özer, 2024).

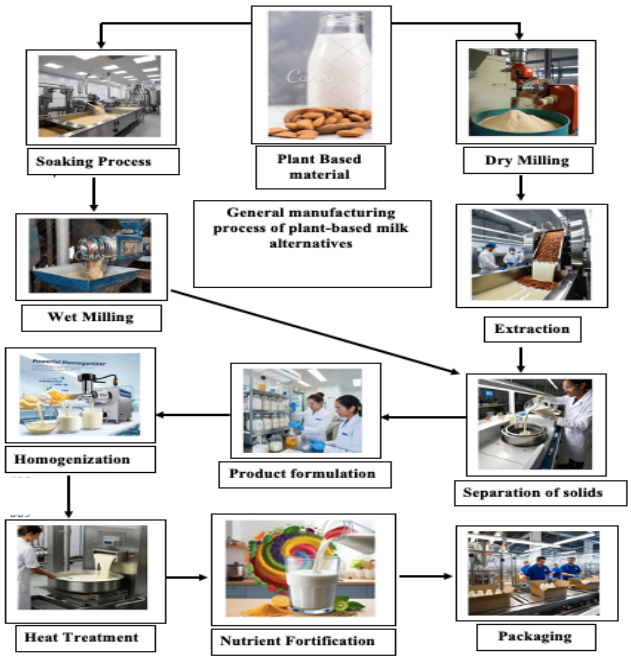

Figure 4. Process Technology for plant-based milk alternative

8. Sensory And Functional Properties of Different Plant-Based Milk

Stylistically and functionally, any plant-based milk, whether it is soy, almond, oat, or hypothetically new entries such as red kidney bean, vary significantly in WoM shear impact. Similar to their development, more plant-based alternatives are becoming available with consumers' increasing awareness about health and sustainability; however, plant-based milks often have less sensory acceptability and nutritional sufficiency than cow's milk. Although plant-based milk is commonly fortified to approximate the nutritional profile of cow's milk, it usually barely reaches the protein amount and bioavailability found in conventional cow's milk (Vashisht et al., 2024). For instance, soymilk is commonly available to consumers because of its nutritional score, which supports its descriptor of plant-based milk with substantially higher protein numbers than cow's milk. Consumers consider many sensory factors (i.e., taste, texture, and mouthfeel) when defining consumer acceptability; therefore, sensory indicators are very important. Jaeger et al. (2024) also found soymilk to be the most sensory-favorable plant-based milk, with almond and oat milk, on average. Owing to their characteristics, relatively novel plant-based milk from red kidney beans may be advantageous for sensory stability and consumer acceptance (Tang et al., 2023). The sensory properties and functional characteristics of plant-based milk exist in the sensory context of acceptance and, in general, in the expansion of plant-based milk into the market. The sensory properties of plant-based milk are also important because consumers of plant-based milk are looking for alternatives for ethical, environmental, and health purposes. As indicated by the above summary, sensory attributes, nutritional features, and the impact of processing on plant-based milk merit attention. Positive sensory attributes for both consumers and producers are particularly valuable for acceptance of plant-based milks, as plant-based milks have superior sensory attributes, although sensory attributes of cow's milk may constrain consumer acceptability. Sensory attributes are deemed relevant for acceptance, including mouthfeel, taste, and texture, and a particularly notable concern for barista-style milk is a smooth mouthfeel (Jaeger et al., 2024). Plant-based milks exhibit considerable health benefits because of their bioactive compounds (i.e., polyunsaturated fatty acids and polyphenols) (Ma et al., 2024). The nutritional content of different varieties varies widely; nevertheless, soymilk often closely resembles cow milk at the protein level (Jaeger et al., 2024). Sensory and functional qualities of soymilk are important. Soy milk is a good choice for anyone to follow a plant-based diet because it is known to have a nutritional profile similar to that of cow milk, especially in terms of protein and fat content. The soybean cultivar used can affect the unique flavor characteristics of soymilk. Better sensory qualities are typically found in varieties with a higher fat content and lower crude protein levels. Almond milk presents sustainability challenges owing to its high water usage in almond farming and health concerns related to its oxalate content, which can increase the risk of kidney stone formation. Enhancing almond cultivation practices and fortifying almond milk with essential nutrients such as calcium and vitamin D (Vashisht et al., 2024). Oat milk has a naturally sweet and creamy flavor, with a smooth consistency owing to its beta-glucan content. Although oat milk has a creamy texture and beta-glucan levels, it is relatively low in protein and may contain phytic acid, which can affect the absorption of minerals (Babolanimogadam et al., 2023). Coconut milk has a rich, tropical flavor that is

mildly sweet and has a thick, creamy consistency, making it ideal for use in curries and desserts, although its high fat content can make it feel heavier (Wang et al., 2020). Rice milk has a neutral, slightly sweet taste and a watery texture (Pramudya et al., 2019). Hemp milk offers an earthy, nutty flavor with a somewhat gritty texture that might not be to everyone is liking; however, its smoothness can be enhanced through fortification and blending (Jemaa et al., 2021).
Cashew milk has a creamy texture, but it is high in fat and often contains added sugars in commercial varieties (Tamuno 2019).

Table 5: Sensory And Functional Properties of Different Plant-Based Milk

Type of Milk	Taste & Texture	Possible Improvements & Challenges	Color Appearance	Consumer acceptance	References
Soy Milk	Soy milk has a mild, beany flavor with a slightly chalky texture, which can vary depending on processing methods; fortification and flavoring often enhance its palatability.	Because soy milk is rich in protein, you run into problems such as the insane taste, such as thread-inacid and triple inhibitors, which can affect the absorbed nutrients, and the presence of anti-instructions. Improvements may include advanced therapeutic methods such as enzyme procedures and fermentation to improve taste, digestibility, and nutritional profile.	Soy milk generally has a creamy white color or off-white appearance, which can occasionally lean towards a slight beige hue due to its natural bean origin and processing.	It is high in protein content and has a close nutritional profile to dairy milk, which makes it widely accepted, especially among health-conscious consumers and vegetarians. Taste improvement and flavor masking have increased its acceptance.	Erfanian & Rasti (2019)

9. Emulsion stability of vegan milk

Stability of the emulsion plays a vital role in the production of vegan milk substitutes. Increasingly, plant-derived proteins from legumes are being used as emulsifying agents in these products. Research indicates that legume proteins can create stable emulsions on par with those formed by milk proteins and synthetic emulsifiers (Benjamin et al., 2014). For instance, soy and pea protein isolates have demonstrated emulsifying properties similar to β-lactoglobulin that produce stable emulsions at mean particle diameters of less than 0.4 μm, and can withstand stability for at least 50 days. Plant-based milk emulsions are more sensitive to a limited number of factors. One study showed that by using enzyme hydrolysis on legume proteins (specifically, faba bean protein concentrates), the colloidal stability of ultra-high-temperature plant milk alternatives was improved (Nawaz et al., 2022). In addition, new emulsion technologies, such as Pickering emulsions, high internal phase emulsions (HIPEs), and nanoemulsions, have been further developed and used to enhance emulsion stabilization and improve the overall quality and functionality of plant-based milks (Bai et al., 2021). Nevertheless, the challenge remains for plant or non-dairy milk alternatives to present a well-balanced nutritional profile and sensory appeal, while also presenting technological, processing, and shelf stabilization dilemmas (Sethi et al., 2016). To promote these factors, researchers are trialling new processing methods, such as ultra-high temperature processing (UHT), ultra-high pressure homogenization (UHPH), and pulsed electric field (PEF), to improve stability, emulsion stability, and sensory acceptance of vegan milk alternatives in the future, while harnessing these methods to develop global sustainability and societal desirability.
Recent studies have examined different strategies to improve the stabilization of vegan milk emulsions using enzymatic-based treatments. Therefore, it is evident that the enzymatic hydrolysis of plant proteins is another approach that could improve the colloidal stability of plant-based milk formulations. In their investigation of faba bean protein concentrate, for example, Nawaz et al. found that partial hydrolysis with alcalase for 5-90 minutes led to changes in the physical and chemical properties of UHT legume-based milk alternatives. In particular, the degree of hydrolysis of of 9-16% FBPC hydrolysates led to more favorable stability characteristics, such as smaller droplet sizes, lower polydispersity index, and better surface characteristics when compared to native materials. It is worth mentioning that the use of enzymes is not limited to hydrolyzing proteins; in fact, some studies have examined enzymes that alter other components of plant-based milk. For example, Sethi et al. considered the role of transglutaminase, an inducer of protein cross-linking, in improving the texture and colloidal stability of plant protein emulsions. These improvements would actively reshape the behavior of emulsion particles and create novel surface characteristics, which would directly influence the overall stability of vegan alternatives to milk. However, one limitation of such treatments is that other factors, apart from the source material, affect the stability of emulsions. For example, Jeske et al. showed that differences in processing, such as those observed with high-pressure homogenization, could lead to different physical and structural properties of plant proteins that enhance the stability of the emulsion. Additionally, the source of the plant proteins is also relevant because, as shown by Benjamin et al., the emulsion properties of legume proteins from soy, pea, and lupine can equal the emulsification capabilities of milk whey protein used in the composition of a vegan drink. Various research efforts concerning the effectiveness of emulsions from plant-based milk have presented new possibilities for the development of non-dairy milk alternatives. Different scientists have investigated various plants and methods of processing them to improve the quality and stability of these emulsions.
A study conducted by Jeske et al. (2019) examined lentil flour as a protein ingredient in milk replacer emulsions. The emulsions underwent high-pressure homogenization at 900 bar, which reduced the particle size to 129.00 nm and provided excellent solubilization and colloidal stability. The researchers claimed that the characteristics and attributes of the emulsions were similar to those of commercial plant-

based milk substitutes. Interestingly, research teams have also examined new methods for enhancing emulsion stabilization. For example, research teams have investigated the use of phytosterols in milk fat emulsions stabilized with whey protein isolate (Zychowski et al., 2016). Even when altering the particle surface shape and size, phytosterols had no effect on the stability and charge of the dispersed particles. If so, this method could improve the nutritional properties of plant-based milk alternatives, while maintaining stability. In summary, the literature suggests that plant-based milk substitutes can now be stabilized by either high-pressure homogenization, enzymatic breakdown of the protein, or by adding other materials or compounds to stabilize the milk substitute. These are important developments in the pursuit of vegan milk alternatives that can be compared to dairy with stability, nutrition, and sensory experience.

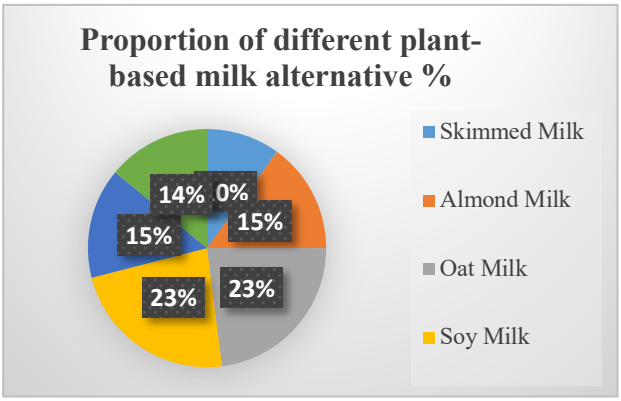

Fig 5. Proportion of plant-based milk alternative

10. Recent advances in vegan milk

The growing consumer interest in vegan products (including, but not limited to, allergies to dairy milk, lactose intolerance, and simple preferences) has led researchers to carefully explore improvements in the quality of plant-based milk substitutes (Xie et al., 2023). Following the growing demand for such products, the market for vegan milk alternatives has greatly expanded, providing consumer choice. It is also sourced from many other origins, providing variability in flavor, texture, and nutritional quality, and addressing dietary preferences across a wide spectrum(Xie et al., 2023). Recent studies have focused on improving the nutritional quality of the majority of these products, which typically do not possess the same nutritional quality as that of dairy milk(Sethi et al., 2016). Some research has shown that "plant-based and non-dairy options may not assume resemble a healthier alternative" "and that natural dairy milk have beneficial attributes associated with nutrients and bioactive compounds"(Park, 2021). On the other hand, some plant-based alternatives offer a decrease in greenhouse gas emissions to environmentally aware consumers (Ammann et al., 2023). In conclusion, current research and development efforts in vegan milk alternatives are designed to improve nutritional sufficiency, sensory acceptance, and mill-processing aspects (Sethi et al., 2016; Xie et al., 2023).

10.1 Limitations and Future Prospectus

A growing number of consumers are finding themselves reducing the amount of animal products in their dietary habits for reasons such as health, ethics, and environmental preservation. The food industry is now developing an increased selection of plant-based dairy alternatives such as almond, hemp, coconut, and rice milk. The success of these alternatives depends on factors such as taste, convenience, and the product. In this project, we studied the current understanding of the physicochemical, sensory, and physiological properties of milk and its various alternatives on a plant-based basis. Plants can be made using natural structures (such as oil bodies) separated from a variety of natural sources. In the future, it will be important to develop young, high-quality plants with good physical and chemical stabilities and desired sensory attributes. Additionally, it is important to design it to have a healthy nutritional profile and a low environmental impact. This study has several limitations that should be addressed in future research projects. The 11-point scale measures images of cow and soymilk, and includes objects that primarily consider aspects of quality, taste, and health. Another limitation is the use of soymilk as an indirect indicator of plant-based dairy products for quantitative research. Soy milk is a product of plant milk and has the largest market share. Nevertheless, the plant milk market is very dynamic, with other products such as almonds, cashews, and coconut milk quickly catching up (Vierhile 2019). Future quantitative studies could include several categories of plant milk in the analysis of product images and determine whether there are differences in the corresponding images of the product. In the product image analysis, both consumer groups rated cow milk and soymilk as rich in minerals. However, soymilk and other plant-based milk products are rich in calcium if fortified.

10.2 Challenges for vegan milk industry

Plant-based milk alternatives face several challenges in terms of their production and market acceptance. One of the primary issues is achieving a nutritional profile comparable to that of cow milk, which necessitates fortification and careful formulation to meet consumer needs (Romulo, 2022). In addition, the inadequately developed sensory features of legume-based milk alternatives pose fundamental barriers to their acceptance and usage (Sethi et al., 2016). Unlike the typically healthy perception of plant-based milks, some studies show that highly processed plant milk may, in fact, be detrimental to health. Some ultra-processed vegan foods, such as certain plant-based milk alternatives, may offer fewer benefits than animal-derived foods and can be harmful to health (Estévez et al., 2024). Despite the growing popularity of plant-based options, some studies have suggested that natural dairy milk surpasses artificial plant milk in nutrients and bioactive compounds (Park, 2021). In other words, the vegan sector of the dairy industry attempts to solve the technological problems of

processing, preservation, enhancing nutritional value, taste, and appealing to better vegan milk alternatives (Sethi et al., 2016). To alleviate such problems, advanced non-thermal food processing methods are being developed. Moreover, the industry needs to address the assumption that plant milk is a healthy substitute for dairy, which is not always accurate. Looking for a balance between sustainable, allergen-free products and those that are nutritionally adequate, enjoyable, and palatable is one of the primary challenges facing the vegan milk industry.

11. Conclusion

In recent years, the use of plant-derived milk substitutes has gained increasing popularity as an environmentally friendly and health-conscious option. While providing unique nutritional benefits and advantages from an ecological standpoint, these substitutes face difficulties when trying to mimic the full nutritional profile of dairy milk. There are ongoing efforts to improve the nutritional and sensory qualities of these products and to resolve other issues, including policy compliance. However, it is crucial to align consumer trends with plant-based dietary sufficiency for the health of the industry, as the market expands. This review article highlights the growing market for plant-based milk substitutes and compares them to dairy milk, advocating their use as eco-friendly and health-oriented alternatives. These substitutes include soy, almond, oat, rice, coconut, cashew, and hemp, each exhibiting varying degrees of nutritional and sensory characteristics. Most plant-based milks lack lactose and cholesterol, and they are abundant in bioactive compounds; however, they do not contain adequate protein, calcium, or vitamin B12, which are the cornerstones of dairy milk nutrition.

Ethical approval

This work does not include any studies with human participants or animals performed by any of the authors.

Declaration of competing interest

The authors declare no conflict of interest.

Authors' contribution

Vaibhav Sharma: Data curation, Investigation, Writing-original draft, Software, Visualization; **Nitin Suradkar**: Conceptualization, Project administration, Visualization, Software, Writing-review & editing; **Anjali Bhoite**:, Resources, Supervision, Validation, Visualization, Writing-review & editing;

Data Availability

No new data was generated.

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REFERENCES:

Ammann, J., Grande, A., Inderbitzin, J., & Guggenbühl, B. (2023). Understanding Swiss consumption of plant-based alternatives to dairy products. *Food Quality and Preference*, 110, 104947.https://doi.org/10.1016/j.foodqual.2023.104947

Antunes, I., Bexiga, R., Pinto, C., Gonçalves, H., Roseiro, C., Bessa, R., Alves, S., & Quaresma, M. (2024). Lipid Profile of Plant-Based Milk Alternatives (PBMAs) and Cow's Milk: A Comparison. *Journal of Agricultural and Food Chemistry*, 72, 18110–18120. https://doi.org/10.1021/acs.jafc.4c03091

Babolanimogadam, N., Gandomi, H., Akhondzadeh Basti, A., & Taherzadeh, M. J. (2023). Nutritional, functional, and sensorial properties of oat milk produced by single and combined acid, alkaline, α-amylase, and sprouting treatments. *Food Science & Nutrition*, 11(5), 2288-2297.

Bai, L., Rojas, O. J., Huan, S., & Mcclements, D. J. (2021). Recent Innovations in Emulsion Science and Technology for Food Applications. *Journal of Agricultural and Food Chemistry*, 69(32), 8944–8963. https://doi.org/10.1021/acs.jafc.1c01877

Bailoni, L., Bacchin, E., Trocino, A., & Arango, S. (2021). Hemp (Cannabis sativa L.) seed and co-products inclusion in diets for dairy ruminants: A review. *Animals*, 11(3), 856.

Banjanin, T., Nikolic, D., Uslu, N., Gökmen, F., Özcan, M. M., Milatovic, D., ... & Dursun, N. (2021). Physicochemical properties, fatty acids, phenolic compounds, and mineral contents of 12 Serbia regional and commercial almond cultivars. *Journal of Food Processing and Preservation*, 45(1), e15015.

Benjamin, O., Everett, D. W., Buettner, A., Beauchamp, J., & Silcock, P. (2014). Emulsifying properties of legume proteins compared to β-lactoglobulin and Tween 20 and the volatile release from oil-in-water emulsions. *Journal of Food Science*, 79(10), E2014–E2022. https://doi.org/10.1111/1750-3841.12593

Nawaz, M. A., Buckow, R., Jegasothy, H., & Stockmann, R. (2022). Enzymatic hydrolysis improves the stability of UHT treated faba bean protein emulsions. *Food and Bioproducts Processing*, 132, 200–210. https://doi.org/10.1016/j.fbp.2022.01.008

Benjamin, O., Everett, D. W., Buettner, A., Beauchamp, J., & Silcock, P. (2014). Emulsifying properties of legume proteins compared to β-lactoglobulin and Tween 20 and the volatile release from oil-in-water emulsions. *Journal of Food Science*, 79(10), E2014–E2022. https://doi.org/10.1111/1750-3841.12593

Bharti, B. K., Badshah, J., & Beniwal, B. S. (2021). A review on comparison between bovine milk and plant based

coconut milk. *Journal of Pharmaceutical Innovation*, 10(3), 374-378.

Chalupa-Krebzdak, S., Long, C. J., & Bohrer, B. M. (2018). Nutrient density and nutritional value of milk and plant-based milk alternatives. *International dairy journal*, 87, 84-92.

Daszkiewicz, T., Florek, M., Murawska, D., & Jabłońska, A. (2024). A comparison of the quality of ultra-high-temperature milk and its plant-based analogs. *Journal of Dairy Science*, 107(12), 10299-10309.

De Jesus, E., Techi Diniz, L. G., Alves, V. F., Schmitz, A. C., Quast, L. B., Dos Passos Francisco, C. T., Tormen, L., & Bertan, L. C. (2023). From nut to Dulce de leche: Development of a vegan alternative – physicochemical characterization, microbiological evaluation and sensory analysis. https://doi.org/10.1016/j.foohum.2023.06.027

Deep, N. Y., Sangita, B., Arvind, K. J., Ranjeet, S. (2017). Plant Based Dairy Analogues: An Emerging *Food. Agri. Res. Tech*., 10, 23–26. DOI: 10.19080/ARTOAJ.2017.10.555781.

Erfanian, A., & Rasti, B. (2019). Effects of soy milk on physical, rheological, microbiological and sensory properties of cake. International Food Research Journal, 26(1).

Eslami, O., & Shidfar, F. (2018). Soy milk: A functional beverage with hypocholesterolemic effects? A systematic review of randomized controlled trials. Complementary Therapies in Medicine, 42, 82–88. https://doi.org/10.1016/j.ctim.2018.11.001

Estévez, M., Arjona, A., Sánchez-Terrón, G., Molina-Infante, J., & Martínez, R. (2024). Ultra-processed vegan foods: Healthy alternatives to animal-source foods or avoidable junk? Journal of Food Science, 89(11), 7008–7021. https://doi.org/10.1111/1750-3841.17407

Fructuoso I, Romão B, Han H, Raposo A, Ariza-Montes A, Araya-Castillo L, et al. An overview on nutritional aspects of plant-based beverages used as substitutes for cow's milk. Nutrients. 2021;13(8):2560.

Gimeno-Martínez, D., Igual, M., García-Segovia, P., Martínez-Monzó, J., & Navarro-Rocha, J. (2023). Characterisation of the Fat Profile of Different Varieties of Hemp Seeds (Cannabis sativa L.) for Food Use. Foods. https://doi.org/10.3390/foods2023-15515

Gram, S., & Mortas, M. (2023). The Effects of Ultrasound and High Pressure Homogenization Processes on Physiochemical Properties of Hemp Seed Milk. Food Chemistry Advances. https://doi.org/10.1016/j.focha.2023.100477

Haas, R., Schnepps, A., Pichler, A., & Meixner, O. (2019). Cow milk versus plant-based milk substitutes: A comparison of product image and motivational structure of consumption. Sustainability, 11(18), 5046.

Harmer, I., Craddock, J. C., & Charlton, K. (2024). How do plant-based milks compare to cow's milk nutritionally? An audit of the plant-based milk products available in Australia. Nutrition & Dietetics. https://doi.org/10.1111/1747-0080.12906

Hess JM, Cifelli CJ, Agarwal S, Fulgoni VL. Comparing the cost of essential nutrients from diferent food sources in the American diet using NHANES 2011–2014. Nutr J. 2019;18(1):68.

Hidalgo-Fuentes, B., de Jesús-José, E., Cabrera-Hidalgo, A. de J., Sandoval-Castilla, O., Espinosa-Solares, T., González-Reza, R. M., Zambrano-Zaragoza, M. L., Liceaga, A. M., & Aguilar-Toalá, J. E. (2024). Plant-Based Fermented Beverages: Nutritional Composition, Sensory Properties, and Health Benefits. Foods. https://doi.org/10.3390/foods13060844

Hidalgo-Fuentes, B., de Jesús-José, E., Cabrera-Hidalgo, A. de J., Sandoval-Castilla, O., Espinosa-Solares, T., González-Reza, R. M., Zambrano-Zaragoza, M. L., Liceaga, A. M., & Aguilar-Toalá, J. E. (2024). Plant-Based Fermented Beverages: Nutritional Composition, Sensory Properties, and Health Benefits. Foods. https://doi.org/10.3390/foods13060844

Hsu E. Plant-based diets and bone health: sorting through the evidence. Curr Opin Endocrinol Diabetes Obes. 2020;27(4):248–52.

Iommelli, P., Zicarelli, F., Amato, R., Musco, N., Sarubbi, F., Bailoni, L., ... & Tudisco, R. (2024). The Effects of Hemp Hay (Canapa sativa L.) in the Diets of Grazing Goats on Milk Production and Fatty Acid Profile. Animals, 14(16), 2373.

J. Cullimore, A. Herby, J. Paul-Quinn, S. Levin, S. Stancic, The nutritional content of animal and plant milks and their health implications, Int. J. Disease Revers. Prevent. 5 (1) (2023) 13.

Jaeger, S. R., de Matos, A. D., Oduro, A. F., & Hort, J. (2024). Sensory characteristics of plant-based milk alternatives: product characterisation by consumers and drivers of liking. Food Research International. https://doi.org/10.1016/j.foodres.2024.114093

Jaeger, S. R., de Matos, A. D., Oduro, A. F., & Hort, J. (2024). Sensory characteristics of plant-based milk alternatives: product characterisation by consumers and drivers of liking. Food Research International. https://doi.org/10.1016/j.foodres.2024.114093

James-Martin, G.; Baird, D.L.; Hendrie, G.A.; Bogard, J.; Anastasiou, K.; Brooker, P.G.; Wiggins, B.; Williams, G.; Herrero, M.; Lawrence, M.; et al. Environmental Sustainability in National Food-Based Dietary Guidelines: A Global Review. Lancet Planet. Health 2022, 6, e977–e986.

Jayeola, O., Yahaya, E., Ogunwolu, O., Igbinadolor, R., & Mokwunye, C. (2018). Physicochemical, microbiological and sensory characteristics of cashew milk formulated yoghurt. African Journal of Food Science, 12(8), 204–209. https://doi.org/10.5897/AJFS2017.1607

Jemaa, M. B., Gamra, R., Falleh, H., Ksouri, R., & Bejı, R. S. (2021). Plant-based milk alternative: nutritional profiling, physical characterization and sensorial assessment. Current Perspectives on Medicinal and Aromatic Plants, 4(2), 108-120.

Jeske, S., Arendt, E. K., Bez, J., & Zannini, E. (2019). Formation, stability, and sensory characteristics of a lentil-based milk substitute as affected by homogenisation and pasteurisation. European Food Research and Technology, 245(7), 1519–1531. https://doi.org/10.1007/s00217-019-03286-0

Jeske, S., Arendt, E. K., Bez, J., & Zannini, E. (2019). Formation, stability, and sensory characteristics of a lentil-based milk substitute as affected by homogenisation and pasteurisation. European Food Research and Technology, 245(7), 1519–1531. https://doi.org/10.1007/s00217-019-03286-0

Jeske, S., Zannini, E., & Arendt, E. K. (2017). Evaluation of physicochemical and glycaemic properties of commercial plant-based milk substitutes. Plant Foods for Human Nutrition, 72, 26-33.

Jyothi, H. K. (2024). A REVIEW ON HEMP (CANNABIS SATIVA L) SEED & ITS MILK. 39–44. https://doi.org/10.58532/v3bcag12p1ch5

K.B. Comerford, G.D. Miller, A.C. Boileau, S.N. Masiello Schuette, J.C. Giddens, K.A. Brown, Global review of dairy recommendations in food-based dietary guidelines, Front. Nutr. 8 (2021) 671999.

Karabulut, G., Nemzer, B. V., & Feng, H. (2024). γ-Aminobutyric Acid (GABA)-enriched Hemp Milk by Solid-state Co-fermentation and Germination Bioprocesses. https://doi.org/10.1007/s11130-024-01187-6

Kasprzak, M. M., Okpala, C. O. R., Domagała, J., Scheler, O., Sady, M., Kruk, J., Bartkova, S., Tkaczewska, J., Jamróz, E., Sanka, I., Onacik-Gür, S., Ptasznik, S., Berski, W., Szram, R., & Zając, M. (2023). Replacement of milk fat by rapeseed oil stabilised emulsion in commercial yogurt. PeerJ, 11, e16441. https://doi.org/10.7717/peerj.16441

Klajn, V. M., Ames, C. W., da Cunha, K. F., Lorini, A., Hackbart, H. C. D. S., Filho, P. J. S., ... & Fiorentini, Â. M. (2021). Probiotic fermented oat dairy beverage: viability of Lactobacillus casei, fatty acid profile, phenolic compound content, and acceptability. Journal of Food Science and Technology, 58, 3444-3452.

Koester, I. G. (2022). An Unusual Case of Infantile Hepatic Steatosis Caused by Coconut-Based Infant Formula. 3(4), e235. https://doi.org/10.1097/pg9.0000000000000235

Kramm, K., Roucher, A., Busom Descarrega, J., Ambühl, M. E., Kammerhofer, J., Meunier, V., & Heinrich, S. (2024). Influence of material characteristics on plant-based milk alternative properties. Journal of Food Engineering, 112019. https://doi.org/10.1016/j.jfoodeng.2024.112019

Lartey, A.; Branca, F. Sustainable Healthy Diets: Guiding Principles; Food and Agriculture Organization of the United Nations: World Health Organization: Rome, Italy, 2019; ISBN 9789251318751.

Lu, Y., Zhang, Y., & Wang, S. (2024). From Palm to Plate: Unveiling the Potential of Coconut as a Plant-Based Food Alternative. Journal of Agricultural and Food Chemistry. https://doi.org/10.1021/acs.jafc.3c09838

M. Lott, E. Callahan, E. Welker Duffy, M. Story, S. Daniels, Healthy beverage consumption in early childhood: recommendations from key national health and nutrition organizations. Technical Scientific Report [Internet], Healthy Eating Research, Durham, NC, 2019 [cited 2 November 2023]. Available from: http://healthyeatingresearch.org.

M.D. Keller, M. Shuker, J. Heimall, A. Cianferoni, Severe malnutrition resulting from use of rice milk in food elimination diets for atopic dermatitis, Isr. Med. Assoc. J. 14 (1) (2012) 40–42.

M.E. Morency, C.S. Birken, G. Lebovic, Y. Chen, M. L'Abbe, G.J. Lee, et al., Association between non-cow milk beverage consumption and childhood height, Am. J. Clin. Nutr. 106 (2) (2017) 597–602.

M.N. Nicholas, C.D.G. Keown-Stoneman, J.L. Maguire, A.M. Drucker, Association between atopic dermatitis and height, body mass index, and weight in children, JAMA Dermatol 158 (1) (2022) 26–32.

Ma, X., Chen, Y., Xu, Z., Wang, C., Xu, W., Chen, Z., Xu, S., Chun-xia, Y., & Deng, Q. (2024). Plant-based milk alleviates antibiotics-induced intestinal barrier damage associated with modulation of gut microbiome and metabolome. Deleted Journal. https://doi.org/10.26599/fshw.2024.9250140

Mäkinen, O. E., Uniacke-Lowe, T., O'Mahony, J. A., & Arendt, E. K. (2015). Physicochemical and acid gelation properties of commercial UHT-treated plant-based milk substitutes and lactose free bovine milk. Food Chemistry, 168, 630-638.

Mäkinen, O. E., Wanhalinna, V., Zannini, E., & Arendt, E. K. (2016). Foods for special dietary needs: Non-dairy plant-based milk substitutes and fermented dairy-type products. Critical reviews in food science and nutrition, 56(3), 339-349.

Mäkinen, O. E., Wanhalinna, V., Zannini, E., & Arendt, E. K. (2016). Foods for special dietary needs: Non-dairy plant-based milk substitutes and fermented dairy-type products. Critical reviews in food science and nutrition, 56(3), 339-349.

McCarron, R., Methven, L., Grahl, S., Elliott, R., & Lignou, S. (2024). Oat-based milk alternatives: the influence of physical and chemical properties on the sensory profile. Frontiers in Nutrition. https://doi.org/10.3389/fnut.2024.1345371

McClements, D. J., Newman, E., & McClements, I. F. (2019). Plant-based milks: A review of the science underpinning their design, fabrication, and performance. Comprehensive reviews in food science and food safety, 18(6), 2047-2067.

Medici, E., Craig, W. J., & Rowland, I. (2023). A comprehensive analysis of the nutritional composition of plant-based drinks and yogurt alternatives in Europe. Nutrients, 15(15), 3415.

Miller GD, Jarvis JK, McBean LD. Handbook of dairy foods and nutrition. CRC Press, 2006.

Molina Vargas, K. A. (2023). Comparative Analysis of Protein Profiles in Commercial Soy Milk and Rice Milk: Insights into Nutritional Composition, Allergenic Potential, and Market Trends.

Moon, Y.-H., Song, Y.-S., Jeong, B.-C., & Bang, J.-K. (2005). Variation on Fatty Acid Profile Including Linolenic acid among Hemp (Cannabis sativa L.) Accessions. The Korean Journal of Medicinal Crop Science, 13(4), 190–193. http://www.koreascience.or.kr/article/ArticleFullRecord.jsp?cn=OOJJBO_2005_v13n4_190

Moshtaghian, H., Hallström, E., Bianchi, M., & Bryngelsson, S. (2024). Nutritional profile of plant-based dairy alternatives in the Swedish market. Current Research in Food Science. https://doi.org/10.1016/j.crfs.2024.100712

Mr, P., Rao, P. J., Edukondalu, L., Aparna, K., & Babu, G. R. (2021). Development of probiotic rice milk and its storage studies. The Pharma Innovation Journal,10(11),902–906. https://www.thepharmajournal.com/archives/?year=2021&vol=10&issue=11&ArticleId=8854

N.S. Wright, M. Smith, Guidelines suggesting children avoid plant-based milks: a closer examination, Matern, Child Health J 24 (10) (2020) 1189–1192.

Najman, K., Ponikowska, P., Sadowska, A., Hallmann, E., Wasiak-Zys, G., Swiderski, F., & Buczak, K. (2024). Physicochemical Properties and Nutritional Relevance of Rice Beverages Available on the Market. Applied Sciences. https://doi.org/10.3390/app14199150

Nawaz, M. A., Buckow, R., Jegasothy, H., & Stockmann, R. (2022). Enzymatic hydrolysis improves the stability of UHT treated faba bean protein emulsions. Food and Bioproducts Processing, 132, 200–210. https://doi.org/10.1016/j.fbp.2022.01.008

Nawaz, M. A., Tan, M., Øiseth, S., & Buckow, R. (2022). An emerging segment of functional legume-based beverages: A review. Food Reviews International, 38(5), 1064-1102.

Ong, D. S. M., Lee, H., Yeo, M. T. Y., & Chiang, J. H. (2024). Nutritional, anti-nutrient, stability and organoleptic characterisation of plant-based milk alternatives derived from adzuki bean (Vigna angularis) and mung bean (Vigna radiata). Future Foods, 10, 100402. https://doi.org/10.1016/j.fufo.2024.100402

Park, Y. W. (2021). The Impact of Plant-Based Non-Dairy Alternative Milk on the Dairy Industry. Food Science of Animal Resources, 41(1), 8–15. https://doi.org/10.5851/kosfa.2020.e82

Park, Y. W. (2021). The Impact of Plant-Based Non-Dairy Alternative Milk on the Dairy Industry. Food Science of Animal Resources, 41(1), 8–15. https://doi.org/10.5851/kosfa.2020.e82

Patil, U., & Benjakul, S. (2018). Coconut milk and coconut oil: their manufacture associated with protein functionality. Journal of food science, 83(8), 2019-2027.

Paul, A. A., Kumar, S., Kumar, V., & Sharma, R. (2020). Milk Analog: Plant based alternatives to conventional milk, production, potential and health concerns. Critical reviews in food science and nutrition, 60(18), 3005-3023.

Paul, A. A., Kumar, S., Kumar, V., & Sharma, R. (2020). Milk Analog: Plant based alternatives to conventional milk, production, potential and health concerns. Critical reviews in food science and nutrition, 60(18), 3005-3023.

Peden, D. L., Derbyshire, S., Funnell, M. P., McLeod, C. J., Rumbold, P., Hansell, E., ... & James, L. J. (2024). Fluid and electrolyte balance following consumption of skimmed milk and a plant-based soya beverage at rest in euhydrated males. European Journal of Applied Physiology, 1-9.

Pineli, L. D. L. D. O., Botelho, R. B., Zandonadi, R. P., Solorzano, J. L., de Oliveira, G. T., Reis, C. E. G., & Teixeira, D. D. S. (2015). Low glycemic index and increased protein content in a novel quinoa milk. LWT-Food Science and Technology, 63(2), 1261-1267.

Pointke, M., Albrecht, E. H., Geburt, K., Gerken, M., Traulsen, I., & Pawelzik, E. (2022). A comparative analysis of plant-based milk alternatives part 1: composition, sensory, and nutritional value. Sustainability, 14(13), 7996.

Pramudya, R. C., Lee, J., Chapko, M. J., Lee, K., Lee, S., Lee, J., ... & Seo, H. S. (2019). Variations in US consumers' acceptability of commercially-available rice-based milk alternatives with respect to sensory attributes and food neophobia traits. Journal of Sensory Studies, 34(3), e12496.

Prieto Jimenez, P. M., Jun-Ihn, E., Matthews, M., Lollie, T. K., Qu, Y., & Martin, M. G. (2022). An Unusual Case of Infantile Hepatic Steatosis Caused by Coconut-Based Infant Formula.

R.D. Jhamnani, S. Levin, M. Rasooly, K.D. Stone, J.D. Milner, C. Nelson. Impact of food allergy on the growth of children with moderate-severe atopic dermatitis, J. Allergy Clin. Immunol. 141 (4) (2018) 1526–1529.e4.

Ramsing, R., Santo, R., Kim, B. F., Altema-Johnson, D., Wooden, A., Chang, K. B., Love, D. C. (2023). Dairy and plant-based milks: implications for nutrition and planetary health. Current environmental health reports, 10(3), 291-302.

Rawal, K., Annamalai, P. K., Ningtyas, D. W., & Prakash, S. (2023). Enhancement of emulsion stability and functional properties of hemp protein-based dairy alternative by different treatments after cellulase hydrolysis. https://doi.org/10.1111/ijfs.16735

Redan, B. W., Zuklic, J., Cai, J., Warren, J. L., Carter, C. W., Wan, J., Sandhu, A., Black, D. G., & Jackson, L. S. (2024). Effect of pilot-scale high-temperature short-time processing on the retention of key micronutrients in a fortified almond-based beverage: implications for fortification of plant-based milk alternatives. Frontiers in Nutrition, 11. https://doi.org/10.3389/fnut.2024.1468828

Rincon, L., Botelho, R. B. A., & de Alencar, E. R. (2020). Development of novel plant-based milk based on chickpea and coconut. Lwt, 128, 109479.

Rivas, M., Garay, R. P., Escanero, J. F., Alda, J. O., & Cia, P. (2002). Soy Milk Lowers Blood Pressure in Men and Women with Mild to Moderate Essential Hypertension. The Journal of Nutrition, 132(7), 1900–1902. https://doi.org/10.1093/jn/132.7.1900

Rodríguez-Martín, N. M., Córdoba, P., Sarriá, B., Verardo, V., Pedroche, J., Alcalá-Santiago, Á., ... & Molina-Montes, E. (2023). Characterizing meat-and milk/dairy-like vegetarian foods and their counterparts based on nutrient profiling and food labels. Foods, 12(6), 1151.

Romulo, A. (2022). Nutritional Contents and Processing of Plant-Based Milk: A Review. IOP Conference Series: Earth and Environmental Science, 998(1), 012054. https://doi.org/10.1088/1755-1315/998/1/012054

Romulo, A., & Sadek, N. F. (2022, February). Fatty acids and amino acids profile of organic black rice (Oryza sativa L.) milk. In IOP Conference Series: Earth and Environmental Science (Vol. 980, No. 1, p. 012032). IOP Publishing.

S. Singhal, R.D. Baker, S.S. Baker, A comparison of the nutritional value of cow's milk and nondairy beverages, J. Pediatr. Gastroenterol. Nutr. 64 (5) (2017) 799–805.

S.K. Vanga, V. Raghavan, How well do plant based alternatives fare nutritionally compared to cow's milk? J. Food Sci. Technol. 55 (1) (2018) 10–20.

Samarasinghe, S., Chandimala, U. R., & Gunathilake, D. (2023). Production of plant-based milk from local almond nuts (Terminalia catappa L.) and evaluation of its sensory and nutritional properties. Tropical Agricultural Research and Extension, 26(2), 104–110. https://doi.org/10.4038/tare.v26i2.5663

Sato, T., Nakajima, M., Takeishi, Y., Nakajima, K., Hasegawa, M., & Watanabe, E. (2023). Effect of the body composition for three months intervention of soy milk. Clinical Nutrition ESPEN. https://doi.org/10.1016/j.clnesp.2023.09.911

Sethi, S., Anurag, R. K., & Tyagi, S. K. (2016). Plant-based milk alternatives an emerging segment of functional beverages: a review. Journal of Food Science and Technology, 53(9), 3408–3423. https://doi.org/10.1007/s13197-016-2328-3

Shiriaev, V. A., Lavrentev, F. V., Morozova, O. V., Ashikhmina, M. S., Goltsman, L. M., Kondrateva, S. A., Kazantceva, U. I., Utkin, R. A., Arseneva, T., & Iakovchenko, N. V. (2024). Perspective and quality aspects of fermentation in rice milk: effects of bacterial strains and rice variety. https://doi.org/10.1111/ijfs.17445

Shori, A. B., Bauberot, J., Aljohani, G. S., Al-zahrani, A. J., Al-sulbi, O. S., & Baba, A. S. (2022). Viability of probiotics and antioxidant activity of cashew milk-based yogurt fermented with selected strains of probiotic Lactobacillus spp. Lwt - Food Science and Technology, 153, 112482. https://doi.org/10.1016/J.LWT.2021.112482

Silva, A. R. A. D., Santelli, R. E., Braz, B. F., Silva, M. M. N., Melo, L., Lemes, A. C., & Ribeiro, B. D. (2024). A Comparative Study of Dairy and Non-Dairy Milk Types: Development and Characterization of Customized Plant-Based Milk Options. Foods, 13(14), 2169.

Silva, A. R., Silva, M. M., & Ribeiro, B. D. (2020). Health issues and technological aspects of plant-based alternative milk. Food Research International, 131, 108972.
Silva, A. R., Silva, M. M., & Ribeiro, B. D. (2020). Health issues and technological aspects of plant-based alternative milk. Food Research International, 131, 108972.

Taha, H. A. I. M., Agamy, N. F., Soliman, T. N., Younes, N. . M., El-Enshasy, H. A., & Darwish, A. M. G. (2024). Preparation and characterization of vitamin E/calcium/soy protein isolate nanoparticles for soybean milk beverage fortification. PeerJ, 12. https://doi.org/10.7717/peerj.17007

Tamuno, E. N. J., & Monday, A. O. (2019). Physicochemical, mineral and sensory characteristics of cashew nut milk. International journal of food science and biotechnology, 4(1), 1.

Tang, J., Cui, L., Zhang, S., Wang, L., Hou, D., & Zhou, S. (2023). A novel plant-based milk alternative made from red kidney bean (Phaseolus vulgaris L.): Effects of cultivars on its stability and sensory properties. Food Bioscience. https://doi.org/10.1016/j.fbio.2023.103362

Tufail, T., Saeed, F., Ain, H. B. U., Niaz, B., Afzaal, M., Din, A., & Suleria, H. A. R. (2019). Cashew nut allergy; immune health challenge. Trends in Food Science & Technology, 86, 209-216.

Tuminah, S., & Sihombing, M. (2015). Frequent coconut milk intake increases the risk of vascular disease in adults. 34(2), 149–158. https://doi.org/10.18051/UNIVMED.2015.V34.149-158

Vanga, S. K., Wang, J., Orsat, V., & Raghavan, V. (2020). Effect of pulsed ultrasound, a green food processing technique, on the secondary structure and in-vitro digestibility of almond milk protein. Food Research International, 137, 109523.

Vashisht, P., Sharma, A., Awasti, N., Wason, S., Singh, L., Sharma, S., ... & Khattra, A. K. (2024). Comparative Review of Nutri-functional and Sensorial Properties, Health Benefits and Environmental Impact of Dairy (Bovine milk) and Plant-Based Milk (Soy, Almond, and Oat milk). Food and Humanity, 100301.

Vitoria, The nutritional limitations of plant-based beverages in infancy and childhood, Nutr. Hosp. 34 (5) (2017) 1205–1214.

Wang, W., Chen, H., Ke, D., Chen, W., Zhong, Q., Chen, W., & Yun, Y. H. (2020). Effect of sterilization and storage on volatile compounds, sensory properties and physicochemical properties of coconut milk. Microchemical Journal, 153, 104532.

Wei, Q., Chen, J., Dai, T., Ma, F., Deng, L., Ke, Y., Wang, Y., Guo, L., Wang, C., Zhan, C., Ren, C., & Li, T. (2024). High-Energy Fluidic Microfluidizer Produced Whole Germinant Oat Milk: Effects on Physical Properties and Nutritional Quality. Foods, 13(22), 3708. https://doi.org/10.3390/foods13223708

Xie, A., Dong, Y., Liu, Z., Shao, J., Yue, X., Li, M., & Li, Z. (2023). A Review of Plant-Based Drinks Addressing Nutrients, Flavor, and Processing Technologies. Foods, 12(21), 3952. https://doi.org/10.3390/foods12213952

Yadav, D. N., Bansal, S., Jaiswal, A. K., & Singh, R. (2017). Plant based dairy analogues: An emerging food. Agricultural Research & Technology: Open Access Journal, 10(2), 1-4.

Yaman, H. (2024). Plant-based milk alternatives: rising trend and nutritional perspective (pp. 191–213). https://doi.org/10.58532/v3bcag7p1ch11

Zandona, L., Lima, C., & Lannes, S. (2021). Plant-based milk substitutes: factors to lead to its use and benefits to human health. Milk Substitutes-Selected Aspects, 1, 1-16.