**Vegan milk - burgeoning sector of functional beverages: a comprehensive review**

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**Abstract**

Worldwide, the market for non-dairy or plant-based milk alternatives is one of the fastest expanding segments in the functional and specialty beverage area of newer food product development. These days, consumers are increasingly likely to choose alternatives to cow milk due to factors including lactose intolerance, hypercholesterolemia prevalence, allergies to cow milk, and preference for vegan diets. Growing in popularity are plant-based milk substitutes, which can be an affordable alternative for those in low-income groups in developing nations and in locations where the supply of cow's milk is insufficient. Even though many novel plant-based food and beverage products are being used as a substitute for cow's milk, many of them have technological problems, whether they be processing or storage-related. When compared to cow's milk, the majority of these milk substitutes lack nutritional balance; nevertheless, they do contain functionally active ingredients with health-promoting characteristics, which appeals to consumers who are concerned about their health. Sensory acceptability in the case of milk substitutes made from legumes is a significant barrier to their widespread acceptance. Researchers are looking into cutting-edge non-thermal processing techniques like pulsed electric field processing, ultra-high temperature treatment, and ultra-high pressure homogenization to address issues with shelf life extension, emulsion stability, nutritional completeness, and sensory acceptability of the finished product. In the upcoming years, a concerted research effort will be needed in the functional beverage market to create fresh products that are both pleasant and nutritionally appropriate.

**Keywords:**cow's milk, functional beverage, lactose intolerance, plant-based milk, ultra-high temperature

**Introduction**

The creation of newer, healthier food alternatives has been a key focus of research in all areas of food product development over the past ten years in order to fulfil changing consumer demands. These demands have been driven by rising urbanisation; the current trend is focused research in functional and specialty beverages for newer goods. Beverages are no longer just used to quench thirst; consumers now expect certain efficacy from their drinks, which fits into their lifestyle. These beverages may be functional in that they meet various requirements and lifestyles, provide energy boosts, combat ageing, weariness, and stress, and target particular diseases and the market is still growing.

These modifications and advancements have resulted in more contemporary goods in the beverage industry. In order to address issues with cow milk allergy, lactose intolerance, calorie concern, and incidence of hypercholesterolemia, milk replacements are one such important functional requirement (Valencia-Flores et al. 2013). The development of plant-based milk with comparable nutritional value to cow's milk presents a problem. Fortification is a processing procedure that is necessary to generate plant-based milk with an adequate nutritional value and high consumer appeal (Romulo, 2022)

The prevalence of lactose intolerance is impacted by ethnic origin. White people from northern Europe, North America, and Australia had the lowest rates among adults, ranging from 5% in the population of the United Kingdom to 17% in Finland and northern France. Over 50% of the population in South America, Africa, and Asia suffers from lactase non-persistence, and in some Asian nations, this proportion is approaching 100% (Lomer et al. 2008). Due to its lack of lactose and cholesterol, plant-based milk has become more popular because it is suitable for everyone and a population at risk for heart disease and lactose intolerance.

 According to Markets & Markets (2013), the market for plant-based milk substitutes is anticipated to develop at a CAGR of 15% from 2013 to 2018 and will be worth $14 billion. Plant-based milk substitutes are widely used in western nations not only as a beverage but also as a component in many different recipes. As a result, there is an opportunity to investigate plant-based alternatives for making milk-like beverages. Additionally, due to the availability of nutrients that promote health, such as dietary fibre, minerals, vitamins, and antioxidants, plant sources (such as grains and legumes) are now recognised as functional foods and nutraceuticals (Das et al. 2012). In this regard, only a few legumes and oilseeds have been widely used to create non-dairy, wholesome, cost-effective, and nutrient-rich plant-based milk substitutes (Sosulski et al. 1978). The functional components and health benefits of various vegan milk is discussed in below table-1

**Table 1**

**Functional components and health benefits of various vegan milk**

|  |  |  |
| --- | --- | --- |
| **Type of milk** | **Functional components** | **Health benefits** |
| Soy milk | Isoflavones | Protects against cancer, cardiovascular disease, and osteoporosis |
| Phytosterols | Lowers cholesterol  |
| Peanut milk | Phenolic compounds | Defensive role against oxidative damage and prevents diseases like coronary heart disease, stroke, and various cancers |
| Rice milk | Phytosterols, β-sitosterol and γ-oryzanol | Lowering effect of cholesterol, hypertension, anti-diabetic, anti-inflammatory, anti-oxidative  |
| Oat milk | β-Glucan | Upturns solution viscosity and delay gastric emptying time, enhances gastrointestinal transit time which are related with their reduced blood glucose level, hypocholesterolemic effect by dropping total and LDL cholesterol |
| Sesame milk | lignans like sesamin, sesamolin, sesaminol | Neutraceutical properties such as antioxidative, hypocholesterolemic, anticarcinogenic, antitumor, and antiviral activities |
| Almond milk | Alpha-tocopherol | Powerful antioxidant which plays a critical role in protecting against free-radical reactions |
| Arabinose | Prebiotic properties |
| Coconut milk | Lauric acid | Promotes brain development, boosts immune system and maintains the elasticity of the blood vessels |
| Vitamin E | Fights against ageing, nourishes skin |

 Source: Sethi et al., (2016)

Soy milk has received a lot of attention in the past since it is a wholesome substitute for cow's milk. However, recent research has focused on investigating how cereals, oilseeds, and nuts might be used for novel food applications based on their functional properties, which show the physical characteristics of food components and their interactions (Toma and Tabekhia 1979). Due to their shared advantages of being lactose free, cholesterol free, and low in calories, all plant-based milks are preferred over cow's milk by customers who are lactose intolerant or allergic to milk proteins. Plant material is broken down to create plant-based milk substitutes, which results in irregularly shaped and sized particles. The type of raw material, the technique of disintegration, and the storage conditions all affect the size of the particles and the stability of the finished product (Cruz et al. 2007).

Peanut milk, rice milk, oat milk, sesame milk, coconut milk, almond milk, hemp milk, hazelnut milk, tiger nut, lupin milk, and quinoa milk are a few alternatives to soy milk that have been the subject of research (Ukwuru and Ogbodo 2011). To make a plant-based milk substitute that is equal to that of cow's milk in terms of look, taste, flavour, stability, and nutritional content, technological challenges must be resolved. This essay seeks to provide an overview of plant-based milk substitutes with technological interventions that have been used thus far to increase their quality, as well as future research that can be done to create high-quality plant-based milk substitutes (Penha et al., 2021).

**Plant-based/non-dairy milk alternatives**

Plant-based milk substitutes are fluids produced by the breakdown (size reduction) of plant material (cereals, pseudo-cereals, legumes, oilseeds, and nuts) extracted in water. These fluids are then homogenised to produce particles with a size distribution between 5 and 20 m, which resemble cow's milk in consistency and appearance. Although there is no explicit description or classification of these plant-based milk substitutes in the literature, an attempt has been made to classify them generally into the following five groups:

1. Cereal based: Oat milk, Rice milk, Corn milk, Spelt milk.
2. Legume based: Soy milk, Peanut milk, Lupin milk, Cowpea milk.
3. Nut based: Almond milk, Coconut milk, Hazelnut milk, Pistachio milk, Walnut milk.
4. Seed based: Sesame milk, Flax milk, Hemp milk, Sunflower milk.
5. Pseudo-cereal based: Quinoa milk, Teff milk, Amaranth milk.

The nutritive value of various vegan milk was given in below table-2

**Table 2**

**Nutritive value of various vegan milk**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Type of milk (per serving of 250 ml)** | **Calories (g)** | **Protein (g)** | **Fat (g)** | **CHO (g)** | **Dietary fibres (g)** | **Calcium (% daily value)** | **Iron (% daily value)** | **Vitamin A (% daily value)** |
| Soy milk (Silk) | 80 | 7 | 4 | 4 | 1 | 30 | – | 10 |
| Quinoa milk (Ecomil) | 104 | 4.5 | 6 | 9 | – | – | – | – |
| Rice milk (Pacific) | 130 | 1 | 2 | 27 | 0 | 30 | 6 | 10 |
| Oat milk (Oatly) | 80 | 2.5 | 4 | 16 | 2 | 15 | 0 | 10 |
| Sesame milk (Ecomil, with agave syrup) | 140 | 1.5 | 6 | 16.5 | 0.5 | – | – | – |
| Almond milk (Silk) | 40 | 1 | 3 | 2 | 1 | 20 | 2 | 10 |
| Coconut milk (Silk) | 80 | <1 | 5 | 7 | 0 | 45 | 4 | 10 |
| Hemp milk (Living harvest) | 70 | 2 | 6 | 1 | 0 | 30 | 6 | 10 |
| Hazelnut milk (Ecomil) | 124 | 1.4 | 6 | 14 | – | – | – | – |
| Multigrain milk (Pacific Organic 7 grain milk) | 140 | 3 | 2 | 27 | 1 | 35 | 8 | 15 |
| Cow’s milk (Amul Gold standardized UHT milk) | 168 | 8 | 10 | 11 | – | 338 mg | 1.25 µg | 168 µg |

*Source: nutritional information available on respective product labels*

### **Types of plant-based/non-dairy milk alternatives**

### **Oat milk**

Due to its possible medicinal benefits, oat milk is a newcomer to the market. Due to its high nutritional value, dietary fibre content, and availability of phytochemicals, oats have attracted a lot of attention. Oats have a number of health advantages, including anti-inflammatory and hypocholesterolemic effects. Dietary fibres including -glucan, functional proteins, lipid and carbohydrate components, and phytochemicals found in oat grains are linked to the health advantages of oats, making them one of the promising raw materials for making functional plant-based milk. A good source of high-quality protein with a balanced amino acid composition is oats. The existence of the functionally active component -glucan, which has neutraceutical qualities, is what initially promoted attention in oats. A soluble fibre called -glucan has the power to thicken liquids, delay gastric emptying, and lengthen gastrointestinal transit, all of which are linked to lower blood sugar levels (Welch 1995). According to Truswell (2002), oat fibres have a hypocholesterolemic impact by lowering both total and LDL cholesterol. They are also a good source of polyphenols and antioxidants. According to Rasane et al. (2015), oat comprises 60% carbohydrate, 11–15% total protein, 5-9% lipids, 2.3–8.5% dietary fibre, and 0.54% calcium. Oats are well-known for their benefits in gluten-free or celiac diets. There have been attempts to create oat-based beverages or oat milk to diversify the oat consumption. (Zhang et al. [2007](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5069255/#CR91); Deswal et al. [2014](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5069255/#CR19)).

**Peanut milk**

Oilseeds are viewed as having a great deal of potential as a substitute source for non-dairy beverages. In terms of oilseeds, peanuts are a viable source of raw material for making plant-based milk, but, like soy milk, their beany flavour restricts their use. By low income groups, undernourished children, vegans, and individuals allergic to cow's milk, peanut milk has been widely used in poor nations (Diarra et al. 2005). The greatest factor in the improved consumption of plant-based milk was the growing awareness of its health benefits. Similar volatile chemicals found in soybeans and peanuts both exist (Leu 1974). Due to numerous amounts of bioactive components that are known for their ability to prevent disease, peanuts are regarded as being healthful.

According to Wien et al. (2014), peanuts are a good source of proteins, lipids, fibre, vitamins, minerals, antioxidants, phytosterols, and other nutrients that may help with blood lipid levels, blood sugar levels, and longevity. According to Settaluri et al. (2012), peanuts have 21.5% carbs, 49.6% fats, 23.68% proteins, and 8% crude fibre. The presence of phenolic chemicals, which are renowned for their antioxidant qualities and a preventive effect against oxidative damage disorders like coronary heart disease, stroke, and various malignancies, is primarily responsible for the functional capabilities of peanuts. Many scientists have tried to make peanut milk using different combinations of treatments.

**Soy milk**

In China, the use of soy milk was originally documented around 2000 years ago. The first plant-based milk that served the objective of supplying nutrition to the populace in areas with insufficient milk supply was soy milk. Additionally, it was well-liked by those who were lactose intolerant and allergic to milk proteins. Essential monounsaturated and polyunsaturated fatty acids, which are thought to be helpful for cardiovascular health, are abundant in soy milk. It offers users a low-cost, hydrating, and nutritious beverage. The positive effects of soybean looked to be caused by isoflavones, which appeared to be its functionally active component. The preventive properties of isoflavones against cancer, cardiovascular disease, and osteoporosis are well recognised. (Omoni and Aluko 2005). According to Cohen et al. (2000), genistein is the most prevalent isoflavone in soybeans and is also thought to be the most physiologically active.

In addition to isoflavones, soy proteins are also known to have therapeutic and preventative advantages against a number of disorders. Additionally, it has been shown that soy products are high in phytochemicals such phytosterols, which are known for their ability to decrease cholesterol (Fukui et al. 2002). According to Liu (2004), dry soybean typically includes 40% protein, 20% oil, 35% carbohydrate, and 5% ash. Rahmati et al. (2014) used soy milk as an emulsifier when making mayonnaise by substituting varied amounts of full-fat soy flour-prepared soy milk for the egg. No statistically significant variation in the acceptability of samples with up to 50% replacement levels was found during sensory evaluation. Consuming soy milk has only one drawback: it is undesirable for people who are sensitive to soy proteins due to the high prevalence of soy allergies. The below figure shows the preparation of soy milk.



Fig. 2. Illinois process for preparation of soy milk (Nelson et al. 1976)

**Almond Milk**

Due to their potential health benefits, eating dried fruits and nuts has become a crucial component of healthy living. The largest portion of all nuts consumed are almonds. According to Sathe et al. (2002), almonds contain 25% protein, the majority of which is in the form of AMP or amandin. The nutrient-rich food almond is also a great source of manganese and vitamin E in the form of alpha-tocopherol.

Almond milk naturally contains more vitamins than other plant-based milks, including vitamin E, which the body cannot produce on its own and must be obtained from food or supplementation. The functionally active component of vitamin E is alpha-tocopherol, a potent antioxidant that is essential for preventing the formation of free radicals (Burton and Ingold 1989).

Other nutrients found in abundance in almonds include calcium, magnesium, selenium, potassium, zinc, phosphorus, and copper. In addition to all of these advantages, the pectic compounds found in the cell walls of almonds, such as arabinose, may have prebiotic qualities that contribute to the functioning by decreasing serum cholesterol levels. Consuming almonds is known to be linked to a number of pharmacological effects, including cholesterol reducing, antioxidant, laxative, and immunostimulant effects. Dhakal et al. (2014) studied the effects of high pressure processing (HPP) on almond milk amandin at 450 and 600 MPa, 30 °C, at varied holding times (0, 30, 60, 180, 300, and 600 s).

**Coconut milk**

South East Asian cuisine heavily relies on coconut milk. It is used as an ingredient in numerous sweet and savoury recipes in addition to being enjoyed as a beverage. Due to its high fat content, coconut milk is frequently used to curries as a thickening to give the dish body. Coconut is a product that is rich in nutrients and a good source of fibre. Iron, calcium, potassium, magnesium, and zinc are among the vitamins and minerals found in abundance in coconut milk. Vitamins C and E are also present in substantial amounts (Seow and Gwee 1997). Coconut milk has been shown to have anti-cancer, anti-microbial, anti-bacterial, and anti-viral properties. It has lauric acid, a saturated fat found in mother's milk and linked to promoting brain development (Belewu & Belewu 2007). Lauric acid also aids in enhancing the immune system and keeping blood vessels supple. Antioxidants like vitamin E found in coconut milk are abundant and help prevent ageing. Consuming coconut milk is hardly ever linked to allergic responses. Additionally, coconut milk has cooling effects, aids with digestion, and nourishes the skin. Despite all of the health advantages, saturated fats restrict consumption.

**Sesame milk**

One of the most significant oilseed crops in the world is sesame. It is eaten in many different dishes, such as tahini, sweet meats, etc. It has a special balance of amino acids and is a source of high-quality protein. Sesamin, sesamolin, sesaminol, and other lignans found in substantial amounts in sesame seeds are known for their useful characteristics. According to Namiki (2007), sesame lignans exhibit anti-oxidative, hypocholesterolemic, anti-carcinogenic, anti-tumor, and antiviral activity. It has a sizable number of antinutritional components such phytates and oxalates (Kapadia et al. 2002). Oxalates are restricted to the outer hull, and the majority of them are eliminated during decortication. Additionally, only the hulls of sesame seeds contain the chemicals responsible for their bitterness, therefore decortication also aids in flavour enhancement.

Sesame proteins are vulnerable to heat denaturation and salt solubility, which restricts their usage in the production of plant-based milks. Sesame protein must therefore undergo functional modification before being used to make plant-based milk. Due to this, the possibility for altering the functional properties of sesame proteins using various processing techniques such as soaking, roasting, defatting, germination, fermentation, and microwave heating has been studied (Quasem et al. 2009). Sesame milk can be consumed despite the drawbacks of soy milk, such as the presence of elements that cause flatulence, the prevalence of soy protein allergies, and beany or off flavour (Zahra et al. 2014).

Other plant-based milks are manufactured and/or sold in several western nations, although there is little scientific literature on these milks. Examples include quinoa, hemp, cow pea, hazelnut, sunflower, and melon seed milk (Bastolu et al. 2016).

**Conclusion**

In order to create a nutritionally complete beverage with high consumer acceptance, advanced processing, technological interventions, and fortification techniques must be developed. Plant-based milk substitutes represent a significant expansion prospect for the health food market. Due to the advantages of plant-based milk alternatives as described above, advanced non-thermal technologies, such as pulse electric field technology, can be useful in identifying factors that are preventing the widespread processing of such plant-based milks, thereby assisting in the provision of affordable, nutrient-rich newer alternatives to all those people who are allergic to cow's milk. For their potential in processing and preserving plant-based milk, the cutting-edge non-thermal technologies that are ideally suited for processing cow's milk must be properly investigated. Fortification with a suitable form of fortificant using appropriate technology and maintaining the bioavailability of nutrients throughout the storage are major areas of research to enable plant-based milk to be used as nutritionally equivalent alternatives for bovine milk by population who is sensitive to milk. Additionally, plant-based milk substitutes will continue to be a significant research field in the more recent product development category of food science and technology in order to meet the approval of the consumer through technological interventions.

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**Conflict of Interest**

All authors has no conflict of interest or any affiliation or involvement in any organization academic, commercial, financial, personal and professionally relevant to the work.

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