

Conventional and novel processes with health benefits of plant-based milk substitutes

Susmi Satheesh Kumar¹, Dr. B Premagowri²

¹ Research Scholar, Foods and Nutrition, PSG College of Arts & Science, Coimbatore, Tamil Nadu, India

² Assistant Professor, Clinical Nutrition and Dietetics, PSG College of Arts & Science, Coimbatore, Tamil Nadu, India

Abstract

Due to its various health benefits on the human body, the consumption of plant-based milk substitutes has quickly grown throughout the world. These drinks are preferred by those who are lactose intolerant, have hypocholesterolemia, or are allergic to cow's milk. Plant-based milk substitutes are a great option despite the extra sugar and low total protein intake since they include phenolic compounds, unsaturated fatty acids, antioxidant activity, and bioactive components including phytosterols and isoflavones. In addition to the health effects, this review includes conventional and novel processes for different plant-based milk substitutes including almond, cashew, coconut, hazelnut, peanut, sesame, soy, tiger nut, oat, rice, hemp, and walnut. The several processing methods for producing cereal, grain, and nut milk substitutes such as roasting, dry grinding, peeling, soaking in water, blanching, wet milling, filtration, addition of ingredients, fortification, sterilization, homogenization, and packaging were discussed. Ultrasound, High-intensity ultrasound irradiation, ohmic heating, pulsed electric field, ultra-high-pressure homogenization, and high-pressure homogenization were applied to plant based milk production. Despite the high phenolic content of plant sources, several processing procedures reduce the end product's antioxidant activity and bioactive component content. Therefore, it is important to properly examine the production of plant-based milk substitutes and to come up with ways to lessen eutrophication and acidity.

Keywords: African breadfruit seeds, bread bar, whole wheat, dietary fibre, indigenous crop

Introduction

Because of various factors, including a dislike of animal cruelty, a desire for a healthy lifestyle, and environmental awareness, consumers have recently tended towards a plant-based diet that includes cereal, legumes, seeds, nuts, fruits, and vegetables (Sebastiani *et al.*, 2019) [21]. One of the food categories that cannot be replaced in the vegan food market is plant-based milk alternatives because they are a necessary component of many vegan food items like plant-based ice cream, yoghurt, cheese, kefir, and butter.

Wet milling, filtration, the addition of ingredients, sterilisation, homogenization, aseptic packing, and cold storage are all processes used to make milk substitutes made from almond, cashew, coconut, hazelnut, peanut, sesame, soy, tiger nut, oat, rice, hemp, and walnut. Salt and sweeteners are utilised to develop sensory characteristics, gums are used to promote stability, and Padma *et al.* (2018)

[17]. In some instances, cutting-edge technologies are used to improve stability without the use of chemicals, including ultrasound, pulsed electric fields, ohmic heating, and high and ultra-high pressure homogenization. For consumers who prefer plant-based milk alternatives to cow's milk, vitamin and mineral enrichment is just as important as fortification and protein enrichment of plant-based milk substitutes. This study aims to give an opinion about the studies on plant-based milk substitute production and its benefits that have been conducted and the studies that can be conducted in the future.

Production of Plant-based milk substitute

There are several methods for producing cereal, grain, and nut milk substitutes. Because they have many common steps, one flowchart as an example is given in the below figure to show the production of plant-based milk substitute.

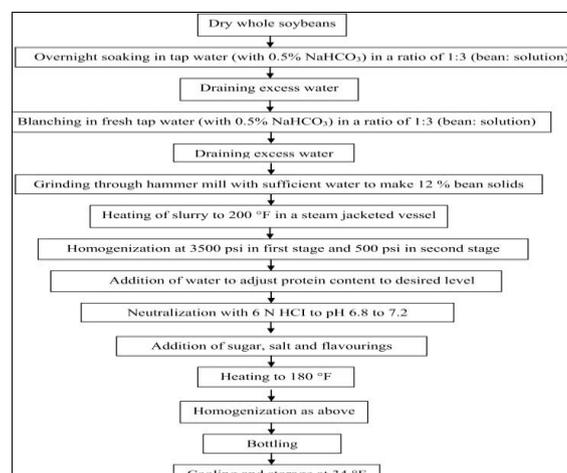


Fig 1: Illinois process for preparation of soy milk (Nelson *et al.* 1976) [15]

1. Roasting

For the preparation of grain milk substitutes, peanut, almond, hazelnut, and sesame milk substitutes, roasting is utilised. Roasting increases the emulsion stability index and protein isolate solubility. In order to reduce the benzaldehyde and pyrazine concentration in an almond milk substitute to less than 0.5 ppm and to obtain a neutral taste, the process is started with heat treatment. According to the results of a study on the production of sesame milk substitute, the roasting process reduces acidity, total solids content, protein, fat, and stability and prevents bitterness and a chalky taste. In addition, hazelnuts and grains such as barley, finger millet, and moth beans can also be roasted (Ilyasoglu and Yilmaz, 2019) ^[7].

2. Dry grinding

In plant-based milk substitute production dry grinding is not much preferable, however, Makinen *et al.*, (2016) ^[12] state that dry milling presents an alternative to wet milling, and there are almond milk substitute which is obtained by dry milling of roasted almonds

3. Peeling

Peeling with the use of acid or base is applied to sesame, walnut, tiger nuts and Brazilian nuts. In addition to acid and base, water may also be used, but, in this case, the process time increases. For example, peeling the skin of walnuts and almonds by soaking in water must be done overnight, a period of 18–20 h, respectively; however, when 2% citric acid at 90 °C is used, the walnuts can be peeled in two to three minutes (Maghsoudlou *et al.*, 2015) ^[11]. The peeling process time also depends on the raw material. Peeling has the additional advantages of releasing the toxic compounds caused by the shell and thus overcoming the bitterness problem in the final product. For instance, oxalic acid found in the sesame hull which is toxic when ingested can be removed by the decortication of the sesame seeds.

4. Soaking in water

A treatment of soaking in water is applied to soybeans, hazelnuts, rice, almonds, tiger nuts, grains, sesame seeds, and peanuts. In this step, the swelling and softening of the cereals and nuts are achieved. Soaking in water enables the rice kernel to soften, and thus the time needed for blanching decreases (Padma *et al.*, 2018) ^[17]. In addition, after soaking, apparent amylose is less, and toxins are released into the water. When tiger nuts are soaked in water, the extraction yield of tiger nut milk increases. According to Sethi *et al.* (2016) ^[22], the addition of alkaline to the soaking water can be applied to sesame seeds, soybeans, and peanuts. It has been observed that the use of NaHCO₃ reduces off-flavor and increases the stability of sesame milk substitute (Ahmadian-Kouchaksaraei *et al.*, 2014) ^[1].

5. Blanching

In the literature, blanching is applied to soybeans, almonds, coconuts, sesames, peanuts, rice, and quinoa. Blanching has numerous advantages like decreasing the microbial load and enzyme inactivation. Blanching also inactivates lipoxygenase which causes the beany flavor in soy milk substitutes. They also mention that blanching decreases the initial microbial load and inactivates the lipase. Instead of blanching, steaming can also be used which increases the total solids and protein yield when compared to boiling and soaking. Moreover, during the cooking of rice, the addition of 0.22% of α - amylase provides an increase in the rate of cooking time (Padma *et al.*, 2018) ^[17].

6. Wet milling

Wet milling is applied to tiger nuts, soybeans, coconut, cashews, hazelnuts, hemp seeds, cowpeas, almonds, walnuts, and peanuts (Zaaboul *et al.*, 2019) ^[24]. In the wet milling process, water is added to the raw material, and then grinding is applied. The amount of added water, milling temperature, pH, milling type, and feed rate are the factors that affect the final product as it has a definite impact on the concentration of the obtained milk substitute

7. Filtration

Filtration is applied to separate the cake and the milk part of the ground raw material. Different filtering materials like double-layered cheesecloth, muslin cloth (25 μ m), and filtering paper with different sizes (150 mesh sieve, filter paper, 180 μ m sieve, four μ m-pore-size filter, and 100 μ m filter) are used (Ilyasoglu and Yilmaz, 2019) ^[7]. Naziri *et al.* (2017) ^[14] used ultrafiltration in the production of hazelnut, sesame, and maize milk substitute.

8. Addition of ingredients

In industrial applications, sunflower lecithin, locust bean gum, and gellan gum are used to enhance physical stability. Ascorbic acid is added to the ingredients to prevent oxidation. Kohli *et al.* (2017) ^[10] mention adding antioxidants and preservatives to the soymilk substitute after filtration. In addition to industrial stabilizers, Bernat *et al.* (2014) ^[2] benefited from 0.05 g/100 mL xanthan gum added before the heat treatment which thickens the hazelnut milk substitute and increases the colloidal stability of the final product. In addition, xanthan gum (0.33% w/w) is used in rice milk alternatives to inhibit the precipitation of particles (Padma *et al.*, 2018) ^[17].

Various sweeteners such as sugar cane and sea salt are added to improve the flavor of the product as well as ingredients such as vanilla or cocoa. Sugar syrup was used to sweeten almond and cashew milk substitutes. Manzoor *et al.* (2017) ^[13] also used vanillin after pasteurization, Quasem *et al.* (2009) ^[20] added two percent sucrose to sesame milk substitute to develop the sensory properties. To improve the silky appearance, sunflower oil (one percent of the initial mass of quinoa) was used in quinoa milk substitute (Pineli *et al.*, 2015) ^[18], and olive oil is included in the ingredient list of plant-based milk substitutes of the Fomilk brand (www.fomilk.com, n.d.).

9. Fortification and enrichment

The protein, vitamin and mineral content of a product are important criteria for people who prefer plant-based milk substitutes instead of cow's milk. To keep the protein amount as high as possible, it is necessary to increase the amount of seed used. During production, different raw materials are mixed in to increase the total protein amount and improve the sensory properties of the product. Another solution to increase the protein amount in the plant-based milk substitute is to use a raw material with high protein content such as lentils whose sensory properties are close to soy milk (Jeske *et al.*, 2019) ^[9]. Calcium, vitamin A, B₂, B₁, B₁₂, D₂, and E are also added to raise the vitamin and mineral content, and the use of calcium tricitrate raises the amount of calcium in the final product (Sethi *et al.*, 2016) ^[22].

10. Sterilization

The purpose of heat treatment is to extend shelf life and keep the quality high. Heat treatment can be applied as pasteurization, sterilization, or ultra-high sterilization.

Sterilization occurs at 121 °C for 15–20 min (Manzoor *et al.*, 2017) [13]. Additionally, although there has been scanty research on plant-based milk substitutes specifically, microfiltration, which is a non-thermal sterilization method, is also a choice for eliminating microorganisms and extending shelf life.

11. Homogenization

Homogenization is applied to enhance the physical stability of the final product and has been carried out using low, high, and ultra-high pressure. As the applied homogenization pressure increases, the stability, clarity, and whiteness index of the milk substitute increase. However, homogenization does not affect viscosity and protein stability. In addition, ultra-high pressure reduces the particle size (Briviba *et al.*, 2016) [3]. While the yield can be increased by applying the process twice or more, an increase in the temperature of the product occurs due to homogenization pressure (Gul *et al.*, 2018) [6]. They said that the temperature of the product increases by five to 10 °C during the homogenization process

12. Aseptic packaging and cold storage

Aseptic packaging is a well-accepted technique for the preservation of liquid and particulate foods. For long shelf-life and high stability, aseptic packaging and cold storage are necessary. The storage temperature must be +4 °C. Additionally Rigid liquid packaging is the most-widely used packaging type of liquid packaging. Rigid liquid packaging includes cartons, paperboard, glass, cans and plastics & PET

bottles. Plastics & PET bottles is the largest segment of the rigid liquid packaging type.

Novel technologies applied in production of Plant-based milk substitutes

The novel technologies applied to plant-based milk substitutes are ultrasound, pulsed electric field, high-intensity ultrasound irradiation, ohmic heating, and ultra-high and high-pressure homogenization. Ultrasound, ultra-high-pressure homogenization, and high-pressure homogenization were applied to almond milk substitute, and the results indicated that the particle size decreased after ultrasound treatment; however, the particle size increased after ultra-high pressure treatment (Iorio *et al.*, 2019) [8]. Ohmic heating and pulsed electric field have been applied to soy milk substitutes (Kohli *et al.*, 2017) [11]. Generally, the applied novel technologies aim to inactivate microorganisms and enzymes, decrease particle size, and reduce viscosity to increase physical stability. Researchers prefer studying a combination of thermal novel technologies, such as ohmic heating and ultra-high- and high-pressure homogenization, to obtain a better quality in the final product (Codina-Torrella *et al.*, 2017) [4]. However, Bernat *et al.* (2015) [2] mentioned that, although a high-temperature causes aggregation of the protein, the application of high-pressure homogenization before thermal treatment and the application of a low-temperature provided an increase in the physical stability of almond milk substitute. The below table shows the novel technologies for extracting plant-based milk substitutes, process conditions and its effects on product.

Table 1: Novel technologies for plant-based milk substitutes

Novel Production Technology	Plant-based Milk Substitutes	Process conditions	Effects on the product
Ultrasound	Almond milk substitute	80% of power, 8 min, the pulse at 6 s for E. Coli 80%, 2 min 6 s for <i>L. monocytogenes</i> . 4.9 min, 300 W, and 20 kHz for physical stability	Microorganism inactivation, reduction in particle size and viscosity are observed.
Pulsed electric field	Soy milk substitute	Electric field intensity of 18, 20 and 22 kV cm ⁻¹ and number of pulses of 25, 50, 75 and 100	A decrease in soybean lipoxygenase is observed.
High-intensity ultrasound irradiation	Coconut-grain milk substitute	Ultrasonic intensity:50–55 W cm ⁻² , Frequency, 20 khz, Amplitude 40%	Particle sizes are found to be smaller.
Ohmic heating	Soy milk substitute	110, 165, and 220 V	Slight increase in the protein aggregate formation, trypsin inhibitor activity (TIA) and chymotrypsin inhibitor activity (CIA) inactivation are observed.
Ultra-high-pressure homogenization	Almond milk substitute	350 MPa, 85 °C 450–600 MPa at 30 °C, 300 s	Submicron/nanoparticle formation, threefold increase of the mean particle size, complete loss of antigenicity, a decrease in free exposed sulfhydryl groups, microorganism inactivation, reduction in protein solubility, and amandin immunoreactivity are observed.
	Tiger nut milk substitute	200 and 300 MPa and 40 °C	Higher colloidal stable, a decrease in particle size, new network formed particles, increase in enzymatic stability, increase in lipid oxidative stability, increase in shelf life from 3 days to 25, 30 and 57 days, increase in brightness and whiteness are observed.
High-pressure homogenization	Hazelnut milk substitute	150 MPa	Decreasing the consistency of products, improving microstructural properties, increased viscosity are observed.
	Peanut milk substitute	150 and 300 MPs	Significantly reduced size, decreased, consistency index (k) and increased in the flow behavior index (n) are observed.
	Almond milk substitute	62, 103 and 172 MPa	Reduction in particle size, increase in particle surface charge, clarity, and whiteness index are observed.

Source: Aydar *et al.*, 2020

Health benefits

In addition, plant-based milk substitutes are also needed by consumers who have lactose intolerance or an allergy to cow's milk. According to research by the U.S. National Library of Medicine (2020) [23], a reduction in the digestion of lactose has appeared in 65% of the world population. In east Asia, 70–100% of people suffer from lactose intolerance. This disease also occurs in west African, Arab Jewish, Greek, and Italian populations. People also choose plant-based milk substitutes for several health-related reasons. For instance, while a heavy consumption of animal-based foods causes cardiovascular diseases and an increase in cholesterol, cereals, legumes, seeds, and nuts contain dietary fiber, vitamins, minerals, and antioxidants. In addition, these foods are placed in the functional and nutraceutical food class (Omoni & Aluko, 2005) [16].

In addition to the role of a plant-based diet on a decrease in cardiovascular diseases, Pistollato *et al.* (2018) [19] observe that a diet rich in plant-based foods including soybeans and nuts reduces the risk of neurodegenerative disorders such as Alzheimer's disease. Moreover, Rita and Luciana (2018) state that even a daily consumption of only two glasses of cow's milk results in an intake of D-galactose above 100 mg/kg which could cause Parkinson's disease. In this context, oilseed and nut milk substitutes—almond (*Prunus dulcis*), cashew (*Anacardium occidentale*), coconut (*Cocos nucifera*), hazelnut (*Corylus*), peanut (*Arachis hypogaea*), sesame (*Sesamum indicum*), soy (*Glycine max*), tiger nut (*Cyperus esculentus*), oat (*Avena sativa*), rice (*Oryza sativa*), hemp (*Cannabis sativa*), and walnut (*Juglans*)—are preferred by vegans and people who suffer from an allergy to cow's milk.

Perspectives for the future

Popular trends, social media, food blogs, and a tendency towards a healthy lifestyle have all contributed to the rise of the plant-based diet, which has led to a boom in the plant-based milk substitute sector. A lack of novel technology application in large-scale experiments, experiments using only a few plant sources, typically substitutes for almond and soy milk, and only one type of plant-based milk present challenges for the industry. Another problem is that, despite the high antioxidant capacity of cereals and nuts, the final result of plant-based milk substitutes has lower antioxidant capacity than the raw materials due to processing stages and low levels of hydrophilic phenolics. The waste products still contain the majority of the beneficial chemicals.

As a result, it's important to recover waste plant-based milk substitute and examine its antioxidant capabilities. To examine the impact of processing on bioactive components in plant-based milk substitutes, various cutting-edge technologies must be used. Plant-based milk substitutes must be protein-fortified and achieve a pleasing taste without the use of added sugar in order to meet customer preferences. This can be accomplished by engaging in sensory analysis for a variety of plant-based milk substitutes and conducting additional research to minimise adverse effects. (Aydar *et al.*, 2020).

Conclusion

The various plant-based milk substitutes go through processing procedures that are both similar and different. All plant-based milk substitutes are produced using wet milling, filtration, and the addition of ingredients, sterilisation, homogenization, aseptic packaging, as well as cold storage; however, some plant-based milk substitutes are produced using dehulling, roasting, dry grinding,

steeping in diluted acid, the addition of some enzymes, and soaking in deionized water. The stability of plant-based milk substitutes has recently been improved through the use of novel technologies such as ultrasound, pulsed electric field, ohmic heating, high- and ultra-high pressure homogenization, and these novel applications could be enhanced for large-scale production.

Although plant-based milk is rich in antioxidant activity that is good for the immune system and fatty acids that help prevent cardiovascular diseases, when compared to cow's milk, plant-based milk substitutes present a problem due to a lack of protein, a low bioavailability of mineral and vitamin content, and added sugar. Despite the high phenolic content of plant materials, some processing steps reduce the final product's antioxidant activity and bioactive compound content. Therefore, it is important to closely examine the production of plant-based milk substitutes and to come up with ways to lessen eutrophication and acidification.

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