Nutritional Contents and Processing of Plant-Based Milk: A Review

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Abstract. For a long time, animal milk such as cow milk has been regarded as a complete food due to its nutritional content and beneficial health effect. However, the emergence of lactose intolerance and allergy to cow milk, new lifestyles such as vegetarianism and veganism, and sustainability challenges such as water pollution and greenhouse gases emission, have pushed researchers to innovate an alternative product to replace animal milk. Plant-based milk, the aqueous liquid obtained from different plant materials such as cereals, legumes, nuts, seeds, and pseudocereals, has been developed to replace animal milk. Therefore, the knowledge of the nutritional profile and processing steps of plant-based milk production becomes essential. This review describes the information regarding the materials used, the nutritional profiles, and the processing steps of plant-based milk. There is a challenge in developing plant-based milk that has a similar nutrition content to cow milk. Processing technique in terms of formulation such as fortification is needed to produce plant-based milk with acceptable nutritional content and high consumer acceptance.

1. Introduction
Milk has been defined as the white liquid secreted from the exocrine gland of mammals such as animals and humans [1]. For centuries, animals milk has become an essential part of human daily regimen [2]. Animal-based milk, for example, cattle milk, sheep milk, goat milk, and buffalo milk, are the most consumed worldwide. Cow milk is the most widely sold and drunk by people, with an average of 212 kg milk per person per year [3]. The consumption of cow milk has been linked as a wholesome or complementary food that provides essential nutrients such as proteins (whey and casein protein), fat (palmitic acid, conjugated linoleic acids (CLA), α-linolenic acid (ALA), milk polar lipids (MPL), vitamins (vitamin A, vitamin B complex) and minerals (iron, calcium, magnesium, phosphorus) [4,5]. These components have been described to have an indispensable function in the body’s growth (both adults and adolescents), metabolism, and maintaining health or well-being. Moreover, many research proved the bio functionalities of the milk, such as antioxidant [6], anti-carcinogenic [7], anti-inflammatory [8], antihypertensive [9], and anti-osteoporosis [10]. Due to this reason, milk has been included as a food recommended by dietary guidelines in many countries [11]. Despite all advantages over the health and functional effects of milk, several drawbacks of milk consumption have been explained [12].

Lactose intolerance (LI) is one of the most common manifestations related to the consumption of milk. LI occurs for those who cannot digest lactose, a disaccharide that represents the major
Carbohydrate source in milk [13]. Several symptoms of lactose intolerance detected on people who suffer LI are diarrhea, gas formation, flatulence, bloating, nausea, and vomiting. It is expected that 70% of the world’s population have a problem with LI due to a genetically decreased lactase enzyme production [14]. LI sometimes is confused with a milk allergy as some symptoms produced are relatively similar. Milk allergy is an immune-related symptom associated with the production of immunoglobulin E (IgE), which appears immediately after milk consumption [15]. The manifestation of milk allergy could be mild and usually triggered by a non-IgE mediated mechanism that affects the skin, respiratory system, and gastrointestinal tract. However, the uncontrolled response by the body could result in severe effects such as systemic anaphylactic response that could lead to death [16]. Milk consumption has also been linked with the increase of low-density lipoprotein due to the saturated fatty acid and cholesterol content in the milk [17]. For these reasons, many people look for a new alternative to animal milk, and alternative product from plant-based has become renew interest in many countries [18].

Plant-based milk has been defined as an aqueous liquid obtained from the extraction of plants, which resembles animal milk [19]. Water is used as an extractant, followed by separating the liquid part from the solid particles. The popularity of plant-based milk is gradually increasing over the years, supported by the emergence of lifestyles diets such as vegetarianism and veganism [20]. Moreover, the consumption of plant-based milk is further exacerbated by environmental concerns. Animals-based production has been considered unsustainable due to a large amount of water used and gas emission release [21]. Almost half of the water used in dairy industries is intended for raising the animal for the meat and dairy. Previous studies revealed that 600-800 liters of water are needed to produce one liter of milk, which is almost 4-fold water needed to produce one liter of soymilk. Manure from dairy farming has been reported to emit greenhouse gas such as methane, carbon dioxide, and nitrous oxide and contributed as the second-largest gas emission source in dairy industries. With a growth of 4.9% per year, the market value for these products is predicted to gain more than 12 billion USD by 2024 [22]. To develop plant-based milk that is commercially accepted by the consumer, the knowledge and understanding of the nutritional profile and processing methods become important. This review provides some information on types of milk substitutes, their nutritional contents, and the processing steps of plant-based milk.

2. Main ingredients used in plant-based making

Plant-based milk could be derived from different materials, which can be classified according to the raw materials used. Although no standard category of plant-based milk in the literature, the widely accepted plant-based milk classification is as shown in Table 1.

| Origin     | Plant-Based Milk                               |
|------------|-----------------------------------------------|
| Legumes    | Soybean, Chickpea, Kidney Bean, Lupin, Pea, Cowpea, Peanut |
| Cereals    | Corn, Rice, Spelt, Sorghum, Rye, Wheat        |
| Nuts       | Almond, Coconut, Pistachio, Walnut, Hazelnut  |
| Seeds      | Flax, Sunflower, Hemp, Sesame                 |
| Pseudocereals | Teff, Amaranth, Quinoa,                        |

Generally, the most ordinary ingredients used in the plant-based milk formulation are water, emulsifier, and additives. The choice of ingredients must be carefully determined to create an end-product that has the desired attributes [23]. Water quality is essential in the production of plant-based milk in terms of water hardness and pH. These parameters must be considered as they can react with other ingredients such as emulsifiers and additives. Therefore, water treatment must be applied before the water can be utilized in plant-based milk production [23].
Emulsifier is another essential ingredient that determines the success of plant-based milk products. Several emulsifiers have been utilized to assist the establishment of oil in water (o/w) emulsion that is stable under normal circumstances, namely proteins, polysaccharides, phosphatides, and microbial surfactants [24]. The selection of emulsifier and their effectiveness to create the smallest droplet size and stable emulsion must be considered, especially the ability to inhibit the aggregation of the droplet during storage and distribution. For example, the stability of plant proteins such as lentil, pea, and legumes, create emulsion which unstable near the isoelectric point [25].

Besides emulsifiers, it is also possible to incorporate other additives to maintain or enhance the nutritional content, quality, and stability of the final product. For example, to improve the viscosity value of the product, thickening agents can be incorporated [26]. The addition may modify the mouthfeel, able to retain creaminess and prevent sedimentation due to protein aggregation. Biopolymers are the most commonly utilized thickening agents and are obtained from plants such as starch, pectin, locust bean, gums, carrageenan, and alginate [27]. Several additives are intentionally added to enhance the nutrient quality profiles of plant-based milk, such as preservatives, vitamins, flavors, colorants, and minerals. In the case of commercial products sold in the market, the fortification of proteins, minerals (e.g., calcium), and vitamins (e.g., vitamin A, D, E, B12) are usually incorporated [27].

3. Nutritional properties of plant-based milk
For a long time, milk has been positioned as a food product rich in nutrients. Scientific evidence supported the routine consumption of milk contributes to the nutrient recommendation and may protect against chronic diseases [28]. It is assumable since milk is a mammal’s nourishment and immune protection for infants [29]. The term milk itself refers to the plant-based milk is utilized as the consumer expects the same nutritional characteristic as bovine milk [30]. Then nutritional properties among plant-based milk are considerably vary depending on the raw materials used. Table 2 shows the comparison of the nutrients content of plant-based milk and cow milk.

| Types            | Nutrient Content (g/100 mL) | Water | Protein | Carbohydrate | Total Fat | Ash | Energy (kcal) |
|------------------|-----------------------------|-------|---------|--------------|-----------|-----|---------------|
| Cow milk         |                             | 88.13 | 3.15    | 4.78         | 3.27      | 0.67| 61            |
| Soybean milk     |                             | -     | 2.92    | 1.67         | 1.67      | -   | 58            |
| Rice milk        |                             | 89.28 | 0.28    | 9.17         | 0.97      | 0.30| 47            |
| Coconut milk     |                             | -     | 0.59    | 9.41         | 4.12      | -   | 76            |
| Almond milk      |                             | 97.05 | 0.59    | 0.58         | 1.10      | 0.68| 18            |
| Cashew milk      |                             | -     | 0.42    | 3.75         | 1.04      | -   | 25            |
| Hemp milk        |                             | -     | 0.83    | 2.5          | 1.25      | -   | 19            |

Plant-based milk has a broad range of energy content. Almond-based milk had the least calorie. The variation of another plant-based milk in terms of calories are ranged from 19-76 kcal per 100 mL. In general, plant-based milk has a lower calorie value than cow milk. There are numerous factors that affected the calorie value of plant-based milk such as the carbohydrate, protein, and fat content, formulation of ingredients, and processing technique used [29]. Another factor that could contribute to the calorie content is the addition of sugar. The amount of sugar is considered an important issue for the choice decision of plant-based milk. Sugar could improve the nutritional values and sensory properties of the product. However, the consumer should be carefully read the composition in the label of how many grams of sugar added, especially for cereal-based milk such as rice milk [30].
Plant-based milk has been considered to have a lack of protein. The protein value of plant-based milk shown in Table 1 is not comparable with cow milk (3.15 per 100 mL), except soybean milk (2.92 g per 100 mL). Soybean milk was the first plant-based milk that could be served for the purpose of obtaining nutrients when the animal milk supply was inadequate [12,31]. Lower protein content in plant-based milk could affect the adequacy of protein intake [29,31]. Generally, due to the low protein value and low amino acid contents, plant-based milk has not been recommended or is not an ideal food for adolescent children [32]. To boost the protein level in plant-based milk, blending with other materials rich in protein was used, such as soybean and peas [29,32].

Related to the fat content in plant-based milk, overall has a very low content of fat, except the coconut milk (4.12 g per 100 mL). Cow milk has a 3.27 g fat per 100 mL, with saturated fatty acids as the most abundant component in milk fat. Saturated fatty acids consumption has been linked to the rise of LDL cholesterol. In contrast, plant-based milk has been reported to have higher unsaturated fatty acids. The main component of soybean and hemp milk are polyunsaturated fatty acids, while rice, cashew, and almond milk contain monounsaturated fatty acids. In the case of coconut milk, the major fat content is saturated fatty acids (short-chain and medium-chain fatty acid) [33].

Regarding vitamins, Table 3 summarized the data of vitamin compositions in plant-based and cow milk. Cow milk is considered a source of vitamin, especially vitamin A, thiamin, riboflavin, niacin, vitamin E, folate, vitamin B6, and vitamin B12, and lack of vitamin D. Usually, fortification of vitamin D was done in cow milk. The replacement of cow milk with plant-based milk could increase the risk of rickettsia due to a lack of vitamin D [32]. Therefore, commercially plant-based milk is usually also fortified with vitamin D. Fortification of vitamin B12 in plant-based milk could increase vitamin B12 value, which is comparable to cow milk.

Table 3. Vitamin composition of plant-based milk and cow milk per 100 mL [29]

| Types       | Unit | Cow milk | Soybean milk | Rice milk | Coconut milk | Almond milk | Cashew milk [34] | Hemp milk [35] |
|-------------|------|----------|--------------|-----------|--------------|-------------|-----------------|----------------|
| Vitamin A   | µg   | 33.00    | 32.57        | 67.5      | 60.00        | 77.14       | 63.00           | -              |
| Vitamin B1  | mg   | 0.04     | 0.08         | -         | -            | -           | 0.03            | -              |
| Vitamin B2  | mg   | 0.16     | 0.24         | 0.30      | -            | 0.19        | 0.14            | 0.18           |
| Vitamin B3  | mg   | 0.08     | 0.28         | -         | -            | -           | 0.39            | -              |
| Vitamin B6  | mg   | 0.04     | 0.10         | -         | -            | -           | 0.04            | -              |
| Vitamin B9  | µg   | 5.00     | 33.60        | -         | 19.20        | 19.20       | 2.00            | -              |
| Vitamin B12 | µg   | 0.36     | 0.68         | 1.00      | 0.75         | 1.00        | 0.63            | -              |
| Vitamin C   | mg   | 1.50     | 0.00         | 0.00      | 0.00         | 0.00        | 0.00            | -              |
| Vitamin D   | µg   | -        | 1.86         | 2.09      | 2.92         | 2.32        | 1.00            | -              |
| Vitamin E   | mg   | -        | 4.00         | 3.00      | -            | 3.84        | 0.13            | 13             |
| Vitamin K   | µg   | -        | -            | -         | -            | -           | 1.00            | -              |

Table 4 summarized the data of mineral content in plant-based and cow milk. Cow milk has been considered a source of calcium due to its low cost, high absorptive rate, and high bioavailability [36]. Calcium is responsible for bone and teeth structure and maintaining normal movement of the body.
Moreover, milk has been determined as a key factor of calcium, potassium, and magnesium adequacy in daily diet [37]. Therefore, the fortification of calcium has become important in plant-based milk. The calcium content of commercial plant-based milk summarized in Table 3 showed a higher amount compared to cow milk. Almond milk, rice milk, coconut milk, and soybean milk have a higher amount of calcium than cow milk. Calcium salts are usually used for the fortification of plant-based milk, such as tricalcium phosphate and calcium carbonate. The addition of these salts is usually in mixtures in the beverages. The use of calcium carbonate was considered better in the fortification due to the higher absorption level [38]. It should be noted that the sedimentation was the drawback of calcium fortification. Therefore, in commercial plant-based milk, the suggestion to “moderately vigorous shake” must be conducted to meet the adequate calcium content and prevent the residue inside the packaging.

| Minerals       | Cow milk | Soybean milk | Rice milk | Coconut milk | Almond milk | Cashew milk [34] | Hemp milk [35] |
|----------------|----------|--------------|-----------|--------------|-------------|------------------|----------------|
| Calcium        | 119.00   | 205.86       | 245.50    | 244.75       | 325.29      | 118.00           | 125.00         |
| Iron           | 0.05     | 0.84         | 0.13      | 0.10         | 0.18        | 0.20             | 1.08           |
| Magnesium      | 13.00    | 49.00        | 35.00     | 35.00        | 21.00       | 11.00            | 17.08          |
| Phosphorus     | 93.00    | 108.00       | 63.00     | -            | 48.00       | 56.00            | -              |
| Potassium      | 151.00   | 364.29       | 50.00     | 46.67        | 65.00       | 27.00            | -              |
| Sodium         | 49.00    | 65.00        | 72.00     | 63.75        | 146.42      | 39.00            | 45.83          |
| Zinc           | 0.38     | 0.75         | 0.75      | 0.66         | 0.56        | 0.13             | -              |

4. Processing steps of plant-based milk
The processing method of plant-based milk production is determined by the raw materials used and the desired target product. Even so, plant-based milk production usually follows the standard unit operation, which is frequently applied in the manufacture of the product [39]. Figure 1 shows the essential techniques to obtain the aqueous extract from plant materials. Generally, it involves soaking, milling, separation, formulation of ingredients, homogenization, heat treatment, and packaging.

Soaking is the initial pretreatment process in plant-based milk production. It can be used for many types of raw materials such as nuts, beans, seeds, and grains [39]. This step helps the optimal extraction process by swelling and softening the outer layer shell, such as cereals, legumes, and nuts. Therefore, the extraction yield could be improved [40]. Besides, the soaking process is also useful for decreasing the initial microbial load, inactivation of enzymes, eliminate off-flavors, improve sensory properties, and enhance the nutritional quality [12,21,41].

Wet milling is the step of the extraction process in plant-based milk manufacturing. It involves the addition of water and size reduction of plant materials. This step has an essential impact on the final composition of the products. The better extraction process could be achieved through the modification of pH using sodium hydroxide or sodium bicarbonate, milling temperature, and enzyme addition [12,21]. These processes enhance the solubility of polysaccharides, protein, and fat and increase total soluble solids in end-products [41,42]. The addition of enzymes such as alpha and beta-amylase improves the quality of cereal-based milk as it helps to hydrolyze the gelatinized starch and prevent gel formation in the product during heat treatment [12,41].
Figure 1. Procedure of plant-based milk production

The filtration process in plant-based milk manufacturing usually conducts the separation of solid particles from the liquid. The removal of solid particles becomes essential to prevent coarse or grainy texture in the final product. Traditionally, the filtration process could be done by using a cheesecloth. In a modern way, ultrafiltration, centrifugation, and decantation could be used. The separated particles or residues are mainly solids particles that are not dissolved and some major nutrients that are not fully extracted [21]. For the product with high-fat content, such as peanut, the separation could be done to decrease the excessive fat content using a cream separator [12].

Food additives are usually added during the formulation process, such as vitamins, minerals, stabilizers, emulsifiers, flavoring agents, coloring agents, salts, and preservatives. As the nutritional quality is significantly different compared to cow milk, the addition of food additives is intended to improve the nutritional quality of plant-based milk, bioavailability, and shelf life of products. The mixture of ingredients during formulation could result in the insolubility of some particles such as protein, starch, fiber, and minerals which decrease the stability of the product [41]. The addition of stabilizer and emulsifier, followed by homogenization process, could improve the stability of plant-based milk by decreasing the particle size, preventing aggregates and lipid droplets formation, and increasing the particle distribution [42].

After homogenization, heat treatment such as pasteurization was conducted to kill the pathogenic microorganism and inactivate enzymes [43]. Besides pasteurization, ultra-high temperature (UHT) and ultra-high-pressure homogenization (UHPH) treatment were also the general technology used in processing of plant-based milk. The use of high temperature is desirable to kill the microorganism. However, the quality aspects such as water-soluble vitamins and protein could changed during the high temperature treatment that may adverse the nutritional quality and shelf life of product [44]. Therefore, optimization of heat treatment process usually involves time and temperature combination to obtain the product with extended shelf life. Optionally, fortification of the product with food additives could be
applied aseptically after heat treatment. Then, plant-based milk is packaged and ready for storage and distribution. Many types of packaging could be applied, such as carton systems (the most common, e.g., Tetra Pak), plastics, and glass. It could also be processed into reconstituted powder form using spray drying or drum drying [45].

5. Conclusion
The consumption of plant-based milk has been increasing over the last few years. The popularity is exacerbated by the increase in lactose intolerance and allergy, new lifestyles such as vegetarianism and veganism, and environmental concern. Plant-based milk could be developed from different sources such as cereals, legumes, nuts, seeds, and pseudocereals. In terms of nutritional content, plant-based milk has some limitations and therefore becomes a challenge in plant-based milk development. Therefore, methods of processing become important to solve this problem. The fortification of plant-based milk is needed to get the product with nutrition content closed to cow milk. It represents the prospective for healthy food, research, and development in plant-based milk need to be widely observed and investigated to optimize the development of a product with high consumer’s acceptability.

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