www.foodandfeed.fins.uns.ac.rs
FOOD AND FEED RESEARCH
Journal of the Institute of Food Technology – FINS
University of Novi Sad
ISSN
2217-5369
(print version ceased in 2023)
2217-5660 (online)

UDK: 637.181:635.657]:577.112

Review article

DOI: 10.5937/ffr0-53776

CHICKPEA MILK: NUTRITIONAL PROFILE, FUNCTIONAL CHARACTERISTICS, BIOACTIVE COMPOUNDS, AND QUALITY ENHANCEMENT – A COMPREHENSIVE REVIEW

Aya Hamioud*[1], Farida Benmeziane[1,2], Lynda Djermoune-Arkoub[1,3]

[1]Bejaia University, Faculty of Sciences of Nature and Life, Department of Biology, Laboratory of Biomathematics, Biophysics, Biochemistry and Scientometry (L3BS), Bejaia, 06000, Algeria
[2]Chadli Bendjedid University of El-Tarf, Faculty of Sciences of Nature and Life, Department of Agronomic sciences, BP 73, EL-Tarf, 36000, Algeria
[3]Bejaia University, Faculty of Technology, Department of Process Engineering, Bejaia, 06000, Algeria

Abstract: The prevalence of cow's milk allergies and lactose intolerance has been growing alongside the evolution of bovine milk consumption and production; consequently, the itching need for an alternative has been the subject of many studies and a growing trend in the milk industry. Plant-based milks have emerged as the most popular and suitable substitutes; they are beverages extracted from cereals, pseudo-cereals, legumes, nuts or seeds. Legumes, due to their high protein content have proven to be one of the successful options. One such legume is chickpea, which not only boasts rich protein content but also contains minerals, fibers, unsaturated fatty acids, bioactive compounds and antioxidant properties. Despite the limited studies available regarding the development of chickpea-based milk alternatives, this review draws upon insights from existing studies that have explored chickpea milk. It covers a range of topics, including the nutritional composition compared to other plant-based substitutes, the health benefits associated with bioactive and functional compounds, and the most novel methods employed in the extraction of non-dairy beverages.

Key words: *plant-based beverage, proteins, pulses, bioactive compounds, novel technologies, functional properties, shelf life*

INTRODUCTION

Milk has been an important food for the human race from the historic period onward. With global milk production hitting 861 Mt in 2020 and projected to grow at 1.7% per annum (p.a.) to 1020 Mt by 2030 (FAO, 2021), dairy remains a major agricultural product. The critique of dairy products, however, is on the rise with a focus on health (lactose intolerance, cow's milk allergy, hypercholesterolemia, hormones and antibiotic residues), environmental impacts (extensive land use, water footprint, CO_2 and methane emissions), ethical implications (Mendly-Zambo, Powell & Newman, 2021), and lifestyle choice (vegeta-

Corresponding author: Phone: +213698725635
E-mail address: aya.hamioud@univ-bejaia.dz

rian/vegan diet, animal welfare) these different reasons are driving the consumers' increasing rejection of dairy products (Lopes et al., 2020). The dairy alternatives market is expected to reach a revenue of USD 44.8 billion by 2027, exhibiting a Compound Annual Growth Rate (CAGR) of 10.4%. This growth is propelled by an increasing shift toward plant-based alternatives as consumers prefer healthier and more sustainable options. This knowledge led to a high demand for vegetable beverage milk replacers. Moreover, these substitutes must be accessible to consumers (low-cost and easy to find), pleasant, and allergen-free. (Rincon, Braz Assunção Botelho & de Alencar, 2020). Protein-rich pulse seeds and the right processsing technologies make it possible to make relevant choices (Duarte et al., 2022).

Plant-based beverages, particularly those that are aqueous dispersions of disintegrated and solubilized plant compartments, have similar appearance and texture properties to bovine milk. While maintaining a low glycemic index, these beverages offer a rich and balanced nutritional profile, including proteins, minerals, and bioactive compounds. Their protein content is comparable to that of cow's milk (3-4% and 3.3-3.5% respectively) and generally surpasses that of nut (0.1%) and cereal-based (1%) beverages. However, the main challenges regarding consuming these beverages are shelf life, preservation, and the processing techniques applied. For example, soy milk is the most widely consumed plant-based beverage and contains a protein level similar to that of bovine milk (minimum 3%). Despite this, consumers have several concerns that revolve around genetically modified organisms (GMOs), allergies, the carbon footprint, and high levels of phytoestrogens such as isoflavones that cause health problems (Lopes et al., 2020). Chickpea (*Cicer arietinum L.*) also referred to as "Gram", "Bengal gram", or "Garbanzo bean", holds a primary position as the most staple consumed in South Asia and ranks third globally after common beans and field peas. Archaeological evidence suggests that chickpeas were among the earliest crops cultivated by humans in the Middle East as early as the eighth millennium BC. It is grown in about 57 countries throughout the world, in a wide range of climatic conditions (Vallath & Shanmugam, 2022), it occurs mainly in two varieties "Kabuli" and "Desi". "Desi" chickpea grains are small, dark and have a ridged surface, grown mainly in semi-arid land. Known for their large seeds, smooth texture, and pale, creamy hue, "Kabuli" chickpea thrives in milder climates and are predominantly cultivated in several key regions. The Mediterranean basin, Middle Eastern countries, North African territories, and various parts of North America are the primary production regions for this particular chickpea species (Grasso, Lynch, Arendt & O'Mahony, 2022).

Chickpeas stand out among legumes for their notable nutritional composition. The edible seeds constitute approximately 80% of the total dry seed weight. Compared to other legumes, chickpeas are particularly rich in proteins and carbohydrates. Their carbohydrate profile is diverse, encompassing monosaccharides, disaccharides and oligosaccharides. Furthermore, chickpeas are abundant in various vitamins, including riboflavin, niacin, thiamine, folate and β-carotene (a precursor to vitamin A) and are a significant source of minerals and dietary fibers. Consumption of chickpeas has been associated with several health benefits, including a potential reduction in the risk of cancer and various chronic illnesses, as well as diabetes management due to their low glycemic index (GI) (Wang, Chelikani & Serventi, 2018). The hypoallergenic properties and impressive nutrient density of chickpea milk have increased its popularity as an alternative to soy milk (Zhang, Zhang, Xie & Sun, 2021).

Chickpea milk is a novel nutritional beverage that contains substantial amounts of carbohydrates, proteins, and isoflavones but has no cholesterol. In contrast to other plant-based milks, it does not trigger allergic reactions (Zhang, Liu, Xie & Sun et al., 2022). Chickpea milk has received noticeable attention because it can alleviate the pressure of stock farming on the environment. In comparison to bovine milk, chickpea milk is darker and exhibits a more pronounced yellow color. One of its distinctive characteristics is its beany flavor, common to many legume-derived products (Rincon et al., 2020) that can be removed by cooking, germination, fermentation and other processing technologies. The consumption of plant-based milk in Algeria, including soy, almond, oat, and coconut milk, is still relatively new and not as widely prevalent as the consumption of cow's milk and dairy products. Hence, the development of chickpea milk is a new and potentially promising approach due to the high nutritional value and the high production of Algerian chickpeas (Ouazib, Moussou, Oomah, Zaidi & Wanasundara, 2015). However, producing high-protein chickpea milk with a reduced beany flavor presents a technological challenge (Mendly-Zambo et al., 2021), and minimizing by-product waste is also an important consideration. While there is much potential for the development of chickpea milk in Algeria, research into the optimal production methods and potential health benefits is still limited.

The work aims to provide a comprehensive overview of chickpea milk, including its nutritional composition in comparison to other plant-based milk substitutes along with cow's milk. It will also explore the functional properties and bioactive compounds present in chickpea milk, as well as the technological interventions that have been applied to improve its quality.

Today, there are more than 20 non-dairy plant-based drinks to choose from according to the literature (Sethi, Tyagi & Anurag, 2016; Gobbi, Ciano, Rapa & Ruggieri, 2019) although there is not yet a clear classification. This classification system provides a comprehensive overview of the diverse plant-based milk substitutes available on the market, organized by their primary plant source.

(a) Cereal derived: include oat milk, rice milk, corn and spelt milk;
(b) Legume based: prominent varieties such as soy, peanut, lupin and cowpea milk;
(c) Nut based: almond, coconut, hazelnut milk, pistachio milk and walnut milk;
(d) Seed based: sesame milk, flax milk, hemp and sunflower milk;
(e) Pseudo-cereal based: quinoa, teff and amaranth milk.

Nutritional and functional properties of chickpea milk

Nutrient composition and comparison with other milk

The rise in popularity of plant-based milk is primarily driven by cow's milk protein allergy (CMPA), the most prevalent form of infant allergy, and lactose intolerance, particularly among adults (Brusati, Baroni, Rizzo, Giampieri & Battino, 2023). Additionally, the nutritional composition of these milk substitutes is comparable to that of cow's milk, particularly regarding proteins, calcium, and energy.

Regarding their nutritional composition, plant-based milks show significant variation mainly in their protein, fat, and sugar content, owing to -differences in grain composition and production processes. These factors are crucial and influential in the resultant nutritional components of these milks. Hence, Table 1 provides detailed information on the nutritional composition and key characteristics of the widely consumed plant-based beverages compared to those of chickpea milk. These types of milk are original, unbranded products extracted in a consistent way without fortification.

According to Wang et al. (2018), chickpea milk is known to have potential as a substitute for soy milk. As shown in Table 1, there is no difference in the protein content between them. Some previous studies (Lopes et al., 2020; Paul, Kumar, Kumar & Sharma, 2020) have indicated a lower protein amount in chickpea milk (1.5 and 2.1 g/100g of milk, respectively), however, it is still higher compared to the average protein content of almonds (which contains “amandin”, an allergenic protein), coconut, rice and cashew alternative milks. Besides, chickpea proteins stand out among other legumes with their superior bioavailability and are particularly notable for their high content of lysine and arginine. However, like many plant proteins, chickpeas are limited in their amino acid composition, as they tend to be low in sulfur-containing amino acids like methionine and cysteine (Jukanti, Gaur, Gowda & Chibbar, 2012). Despite that, cow's milk protein content has higher quality than plant-based milk alternatives because of its complete essential amino acid profile which includes isoleucine, leucine, threonine, lysine, methionine, cysteine, phenylalanine, tyrosine, valine (Reyes-Jurado et al., 2021).

Regarding the fat content, overall, plant-based milks have a very low-fat content except for the almond and coconut milk (3.20-7.42 and 2.54-8.25 g/100 g, respectively). Chickpea milk is categorized as a fat-free alternative (containing 0.39-0.5 g/100g) and is particularly comparable to oat and rice milk, which also contain similarly low levels of fat (0.1 and 0.3 g/100 mg, respectively) when compared to other milk substitutes. The lipid profile of chickpeas is characterized by a predominance of unsaturated fats. The fatty acid composition is as follows: polyunsaturated fatty acids constitute the majority (66% of the total fat content), followed by monounsaturated fatty acids (19%), and with saturated fatty acids representing the smallest fraction (15%). Linoleic acid (18:2) emerges as the most abundant with a proportion of 51.2% (Silva, Silva & Ribeiro, 2020). At the tissue level, the metabolism of linoleic acid contributes to various physiological processes. When processed by the body, this essential fatty acid serves as a precursor for the synthesis of prostaglandins. These hormone-like substances have signify-cant physiological effects, particularly on the cardiovascular system. They are known for their ability to induce smooth muscle contraction and promote vasodilation. Consequently, they contribute to the regulation of blood pressure, resulting in its reduction (Zia-Ul-Haq et al., 2007). Cow's milk has 3.27 g of fat per 100 mL, with saturated fatty acids as the most abundant component in milk fat. Saturated fatty acid consumption has been linked to the rise of LDL cholesterol. In contrast, plant-based milk has been reported to have higher unsaturated fatty acids (Romulo, 2022).

About 80 % of chickpea seed composition, on a dry basis, consists of protein and carbo-hydrates (Kishor, David, Tiwari, Singh & Rai, 2017). Among other milks, rice has the highest total carbohydrates (9.58-10.9 g/100g) which makes it comparable in terms of the total calories available upon consumption of a similar volume of cow's milk (Vanga & Raghavan, 2018). Rates ranging from 3.9 g/100g to 9.01 g/100g of carbohydrates are recorded in chickpea milk. In the case of the other plant-based milk beverages, the total carbohydrate content was found to be: 3-8, 5.1, 4.18-4.58, 1.42, and 0.65-0.69 (g/100g) in soy milk, oat milk, cashew milk, almond milk and coconut milk, respectively (Table 1). Carbohydrate constitutes about 60 – 65 % of chickpea seeds. Compared to cereals, legumes have slightly lower carbohydrate content. Chickpea consist of available and unavailable carbohydrates (Mudryj, Yu & Aukema, 2014).

Available carbohydrates are those that can be digested by enzymatic action in the small intestine and they include monosaccharides (glucose, fructose, and galactose) and disaccharides (sucrose, maltose). Unavailable carbohydrates comprise oligosaccharides such as raffinose, stachyose, verbascose, and cice-ritol, as well as resistant starch, pectin, hemi-cellulose, and cellulose. These carbohydrates cannot be digested in the small intestine (Miao, Zhang & Jiang, 2009). Instead, they pass in undigested form until they reach the colon, where they act as food (prebiotics) for the probiotic or beneficial bacteria that reside there which per se is a positive effect (Kamboj & Nanda, 2017). Hence, according to Kaur and Prasad (2021), chickpeas contain starch as the major polysaccharide, with stachyose and raffinose being among the oligosaccharides present. Studies have shown that soaking and heat treatment, such as cooking, germination and fermentation can effectively reduce the levels of oligosaccharides (Duarte et al., 2022).

To address potential nutritional gaps in diets based on non-dairy beverages, many manufacturers fortify their plant-based milk alter-natives by supplementing them with proteins and essential micronutrients such as vitamin D, calcium, and vitamin B12. This fortification helps mitigate the risk of deficiencies that might arise from excluding cow's milk from the diet (Mäkinen, Wanhalinna, Zannini & Arendt et al., 2015). Calcium fortification, in particular, is common, as cow's milk is reco-gnized as a principal dietary source of this mineral (Vanga & Raghavan, 2018).

The calcium content in chickpea milk can surpass that of cow's milk, with levels reaching 131.2 mg per 100g compared to 123 mg per 100g, respectively. However, the levels of calcium range widely among different types of plant-based milk. Rice milk, coconut milk, oat milk, cashew milk, almond milk and soy milk 118, 100.06-121.02, 49.0-49.2, 21.85-21.95, 8.6-20.0 and 5.96-5.98 mg/100g of calcium, respectively. As demonstrated, soy milk has the lowest amount of calcium. Regarding potassium content, the values found in chickpea milk are quite different from those of cow's milk which contains 150 mg/100 g.

The high levels found in chickpea milk (206.99 mg/100 g) can be explained by the fact than chickpeas are a natural source of potassium, containing approximately 1116 mg/100 g of potassium, natively. Potassium is notable for its prevalence within the intracellular fluid and is known as an essential nutrient. This mineral plays a significant role in main-taining optimal cellular function (Rincon et al., 2020).

Table 1.
Comparison of nutritive potential of chickpea milk with bovine milk and the most consumed non-dairy plant-based milk substitutes

Milk type	Proximate composition (g/100 g)					Minerals (mg/100g)									References
	Protein	Moisture	Fat	Carbo-hydrates	Ash	Na	Ca	K	Mg	P	Fe	Cu	Zn	Mn	
Chickpea milk	2.1-3.3	87.3-93.94	0.39-0.5	3.9-9.01	0.16-0.62	1.19-14.20	15.27-131.26	35.23-206.99	7.46-8.42	19.17-20.61	0.35-0.37	0.06	0.16-0.18	0.18-0.20	Paul et al. (2020); Lopes et al. (2020); Duarte et al. (2022)
Bovine milk	3.28*	85.95-86.29	3.2*	4.67*	0.63-0.77	38.0*	123.0*	150.0*	12.0*	101.0*	0.073	0.001*	0.4*	0.8	USDA (2020); Collard and McCormick (2021); Mohamed,
Almond milk	1.34-1.42	72.04-86.11	2.54-8.25	1.42	3.02-3.04	6.2-6.5	8.6-20.0	220-303	104-160	279-408	1.40-3.98	0.02*	4.0-4.80	0.056*	Kundu. Dhankar & Sharma (2018); Makinde & Adebile (2018);
Oat milk	1.85-1.88	89.73-91.47	0.09-0.19	5.1*	0.33-0.51	42.0*	49.0-49.2	162.0*	5.9*	112.0*	0.60-0.70	0.027*	0.09*	0.126*	USDA (2022); Gupta and Bisla, (2019)
Soy milk	3.10-3.24	91.29-92.48	2.30-2.40	3.0-8.0	0.79-0.81	45.0-100.0	5.96-5.98	118.0*	17.5*	46.0*	1.57-1.59	0.096*	0.26*	0.16*	Kundu et al. (2018); USDA (2021); Vanga & Raghavan, (2018)
Coconut milk	0.73-1.35	88.8-92.3	3.20-7.42	0.65-0.69	0.23-0.41	6.76-10.34	100.06-121.02	130.29-182.83	35.0	100.0*	0-0.13	0.266*	0.38-0.94	0.916*	Rincon et al. (2020); USDA (2019)
Cashew milk	1.85-2.25	86.82-87.42	3.12-3.48	4.18-4.58	2.58-2.68	22.8	21.85-21.95	68.07-68.13	38.1-38.3	18.17-18.43	0.75-0.85	-	0.75-0.95	-	Manzoor, Manzoor, Siddique & Ahmad (2017)
Rice milk	1.68-1.98	18.75	0.34-0.38	9.58-10.9	0.45-0.51	39.0*	118.0*	27.0*	70.0*	56.0*	0.2*	0.037*	0.13*	-	Atwaa, Ahdab, Elmaadawy&Awaad, (2019); USDA (2019)

**Data taken from the United States Department of Agriculture (USDA)*
-: non-determined

Furthermore, various other minerals are available in considerable quantities in chickpea milk including magnesium (7.46-8.42 mg), phosphorous (19.17-20.61 mg) and sodium (1.10-14.20 mg)

It is known that the addition of food additives by the food industry greatly increases the levels of sodium in food (Ning, Mainvil, Thomson, & McLean, 2017). The food industry often adds sodium or its compounds to food to enhance the product's flavor (Kameník, Saláková, Vyskočilová, Pechová & Haruštiaková, 2017), which explains the high amounts of sodium in commercial plant-based milk compared to that extracted by hand.

Most of the alternative milks contain comparable quantities of minerals, except cashew milk, which has no copper or manganese reported, and lower amounts of potassium in rice milk. On the other hand, almond milk contains the highest amount of phosphorus among the alternative milks mentioned.

When considering these amounts from a nutritional standpoint, chickpea milk is the best replacement for soy milk; if it is fortified with other minerals such as phosphorus and iron, it can be used as an excellent alternative to cow's milk. Nevertheless, it's important to point out that the extraction process can play a key role in determining its overall composition.

Bioactive compounds and health benefits

Pulses are regarded as a good source of bioactive substances such as polyphenols, phytosterols, and indigestible carbohydrates with various, physiological and metabolic benefits. These bioactive substances vary in concentration concerning species and varieties of pulses (Moreno-Valdespino, Luna-Vital, Camacho-Ruiz & Mojica, 2020). Pulses are often consumed after being processed, which boosts the bioavailability of nutrients and bioactive molecules, and also enhances the palatability of foods (Wang et al., 2018; Zaheer & Humayoun Akhtar, 2017).

In addition, legume seeds, including chickpeas, contain a variety of bioactive compounds that can affect human health through numerous metabolic effects. Compounds such as protease inhibitors (PIs), seed reserve proteins (γ-conglutin), lectins, phytates, oligosaccharides, saponins, and phenolic compounds may influence consumer's health (Champ, 2002; Guzmán, Martínez-Ayala, García-López, Soto-Luna & Gurrola-Díaz, 2021). While some of these substances are beneficial, others are classified as anti-nutritional factors due to their potential to hinder digestion and nutrient absorption. For instance, PIs can reduce protein digestibility and absorption, while phytates can bind to microelements, reducing their bioavailability and showing resistance to conventional cooking processes (Duarte et al., 2022). Therefore, their overall effective reduction requires more advanced processing techniques such as enzymatic degradation, chelation, germination and, fermentation (Mäkinen et al., 2015; López-Martínez, Leyva-López, Gutiérrez-Grijalva & Heredia, 2017), or intensive soaking as they are fairly soluble in water. Duarte et al. (2022) conducted a study on chickpea and lupin beverages and found that the anti-nutritional compounds (phytic acid and lectins) were significantly reduced during beverage processing. They also reported that this reduction did not affect the bioavailability of minerals and did not result in intestinal malabsorption.

Chickpeas owe many of their health-promoting properties to a diverse array of bioactive compounds, including flavonoids, carotenoids, phenolic acids, stilbenes, and lignans. The *Desi* variety has been found to contain higher concentrations of antioxidant compounds compared to the *Kabuli* type (Kaur & Prasad, 2021).

According to Zhang et al. (2022), isoflavones are one of the main active ingredients in chickpea milk. They are a class of natural flavonoids with phytoestrogen activity (Sasi et al., 2022) and a secondary metabolic product of polyphenols. Fu and Zhang, (2013), have indicated that the isoflavones chickpea milk exist mainly in four chemical forms including three aglycones (biochanin A, genistein, and formononetin) and glucosides (genistin, ononin, and biochanin A-β-D-glucoside) among them, biochanin A is the major isoflavone with the highest content, accounting for about 30% of the total isoflavones. Multiple previous studies have documented that isoflavones possess numerous health advantages, including anticancer properties, antioxidant activity and the potential to prevent atherosclerosis, cardiovascular disorders, and osteoporosis (Fig. 1) (Duarte et al., 2022; Sasi et al., 2022).

According to Mota et al. (2021), several advantages for human health are attributed to chickpea proteins. The deflammin protein has been shown to have anti-inflammatory properties in *in vitro* models using various colon cancer cell lines, as well as in *in vivo* models of acute and chronic diseases. Duarte et al. (2022) examined the *in vitro* inhibitory activity of soluble protein fractions from chickpea beverages on gelatinase MMP-9, a matrix metalloproteinase related to inflammation and cancer. They also investigated its potential effects on colon cancer cell proliferation and migration. The experimental results demonstrated significant inhibitory activity on commercial MMP-9, which was considerably higher after *in vitro* digestion, resulting in a 48% inhibition.

Hence, despite undergoing an extraction process and being subjected to digestive conditions, polypeptides in chickpea milk maintain their bioactivity. This notable characteristic, along with its high nutritional value and digestibility, contributes to chickpea milk's classification as a functional beverage. The findings from these studies indicate the preservation of bioactivity in chickpea milk, even after undergoing manufacturing and digestive processes.

To date, only a limited number of studies have investigated the bioactive compounds present in chickpea milk. While these studies offer valuable insights, they are still insufficient to establish a comprehensive understanding of chickpea milk's overall bioactivity. Hence, further research is needed to fully elucidate the health benefits and bioactive properties of chickpea milk.

Functional properties

The functional properties of proteins are the physicochemical characteristics that determine their behavior in a food product when processed for storage and consumption purposes. Besides the processing conditions (pH, temperature, time, and interaction with other compounds), the amino acid profile of proteins affects their functionality which can lead to an effect on its conformation and structure. The textural and organoleptic properties of food products are impacted by the techno- functional characteristics of proteins, including solubility, water-holding capacity, oil-holding capacity and emulsifying properties. Consequently, these are the most significant properties of proteins in foods (Onder et al., 2023).

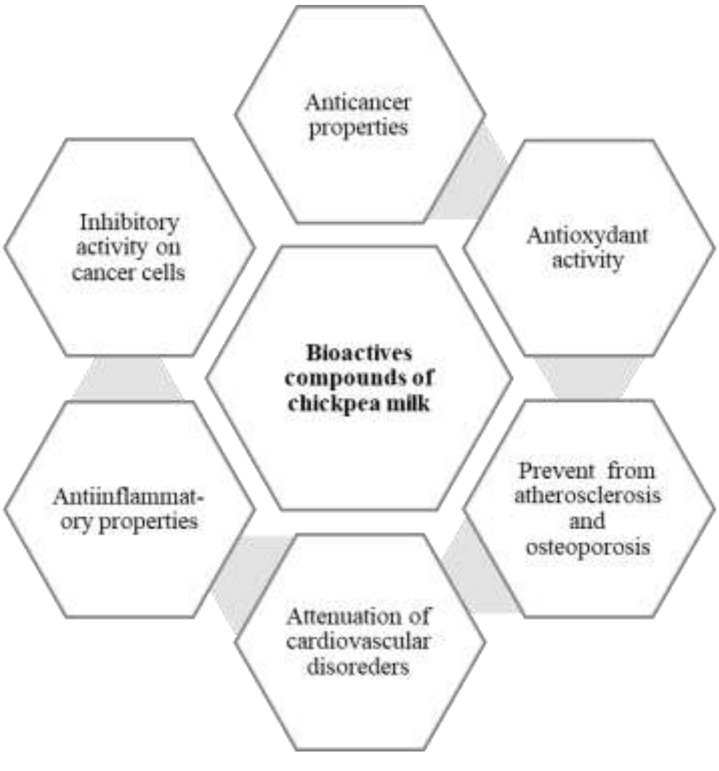

Figure 1. Health benefits of bioactive compounds in chickpea milk

Solubility

Protein solubility plays a crucial role in determining the expression of other functional properties, like the emulsifying ability of a component. It refers to the amount of protein in a sample that can dissolve into a solution. Furthermore, protein solubility depends on the protein amino acid composition and structure of the protein. As an index of protein performance, it significantly affects other functional properties (Grasso et al., 2022; Vallath & Shanmugam, 2022; Onder et al., 2023). According to Onder et al. (2023), a study has been conducted on the solubility values of the chickpea protein isolates with different pH values. This investigation, alongside similar studies conducted by other researchers, has shown the solubility to be at its lowest between pH 4 and 6, while it reaches its highest between pH 8 and 10. The solubility of isolates at the acidic pH (3.0) changed within a wide range of 13.2−58.2% (Boye et al., 2010; Withana-Gamage, Wanasundara, Pietrasik & Shand, 2011; Ghribi et al., 2015; Tontul, Kasimoglu, Asik, Atbakan & Topuz, 2018).

Water holding capacity (WHC)

The WHC refers to the ability to retain water molecules against gravity. This ability depends on the protein conformation and can also be expressed as the quantity of water absorbed per gram of protein isolate. The WHC determines the structure and sensory attributes of any chickpea protein-containing food. While a high WHC can result in dry products, low WHC may lead to a low efficiency in water retention (Grasso et al., 2022; Onder et al., 2023). The hydration properties of chickpea proteins can be affected by the amount of carbohydrates present. This relationship is observed as a negative correlation: higher carbohydrate content is associated with reduced WHC; Conversely, proteins with comparatively lower carbo-hydrate content exhibit higher WHC (Jarpa-Parra, 2017). Indeed, Kaur and Singh (2007) indicated that the levels of water absorption of isolated chickpea protein ranged from 1.5 to 3.4 g of water bound per gram of protein sample on a dry basis.

Oil holding capacity (OHC)

Similar to the WHC, the OHC is defined as the amount of oil absorbed per gram of protein. According to Ma et al. (2022), chickpea protein isolates can absorb up to 5.37 g of oil per gram of protein. The *Kabuli* chickpea exhibits a higher OHC compared to the *Desi* cultivars. This difference is attributed to the *Kabuli* variety's elevated proportion of non-polar amino acids (Withana-Gamage et al., 2011).

Emulsifying properties

The emulsifying properties of proteins and their performance are usually determined based on their ability to form and stabilize emulsions. Proteins' role in emulsion formation is characterized by their organization at the interface between oil and water. This leads to the formation of a film around newly formed oil droplets and reduces interfacial tension. Consequently, this process helps to prevent undesirable occurrences such as coalescence, creaming, flocculation, and sedimentation in emulsion systems where oil droplets are dispersed in an aqueous medium, and proteins form protective films around them (Bessada, Barreira & Oliveira, 2019; Onder et al., 2023). Many intrinsic (charge, polarity, structure, conformation, stability and solubility) and environmental factors (pH, temperature), can affect the ability of proteins to perform as emulsifiers (Ma et al., 2022). Onder et al. (2023) reported the emulsifying capacity of chickpea protein isolates to be 401.2 and 469.1 g/g.

Processing technologies for chickpea milk production

Besides choosing raw materials with desirable flavor and nutritional qualities, the extraction process of plant-based milks plays a crucial role in producing suitable ingredients for creating satisfactory dairy alternatives. To amplify the organoleptic quality of plant-based dairy analogues, it is crucial to apply appropriate raw material extraction and processing strategies. These strategies encompass a variety of methods, including mechanical, chemical, biological, and innovative techniques. The aim is to create a matrix with the best functional properties for subsequent production of dairy alternatives. The extraction process significantly affects the raw materials' composition, which then determines its behavior across various stages of product development. Therefore, it is vital to carefully select and apply suitable extraction and processing strategies to achieve the desired outcomes when crafting high-quality plant-based dairy analogues (Pua et al., 2022; Yadav, Redden, Chen & Sharma (Eds.), 2007).

Overview of traditional and modern methods

Conventional mechanical operations

Numerous studies have investigated the extraction of chickpea milk. According to these studies, the standard extraction process consists of several steps: soaking, cooking, milling or grinding, sieving followed by pasteurization and storage (Fig. 2). (Fu & Zhang, 2013; Al-Ani, 2020; Lopes et al., 2020; Reyes-Jurado et al., 2021; Zhang et al., 2021; Pua et al., 2022; Zhang et al., 2022). In the traditional processing of chickpea milk, the initial step following washing involves seed soaking in water overnight for 72 hours as described in Duarte et al. (2022). Also, during soaking, the water-to-seed ratio may vary, depending on subsequent steps, between 1/2 to 1/12. It is of utmost importance to add plenty of water (tap or distilled) as the seeds will expand and absorb a lot. After soaking, they will be soft enough to be compressible by fingers. This step helps reduce the anti-nutritional factors and off-flavors and contributes to an increase in milk yield (Sethi et al., 2016). After soaking, the water is drained off, and the pulse milk is produced either after cooking or roasting in further processing. These steps lead to the development of distinct flavor, taste and nutritional composition of the final product. They also enhance nutrient solubility and im-prove water holding capacity and gelation rate. Furthermore, Pua et al. (2022) have highlighted that the heat application inactivates undesirable endogenous enzymes, thus further improving the flavor and nutritional attributes of the milk.

Subsequently, the cooked or roasted sample is ground using a colloidal mill or any appropriate grinding equipment, adding an appropriate amount of either fresh or cooking water. Indeed, it was observed that milling with cooking water increases protein content in milk (protein solubilization during the cooking process) and gel formation (Duarte et al., 2022). The final product is finalized by straining through a mesh strainer or cheesecloth. Except for the difference observed in the material and the conditions of the extraction processes from different studies, supplementary operations such as blanching, germination, dehulling and homogenization may be additionally included.

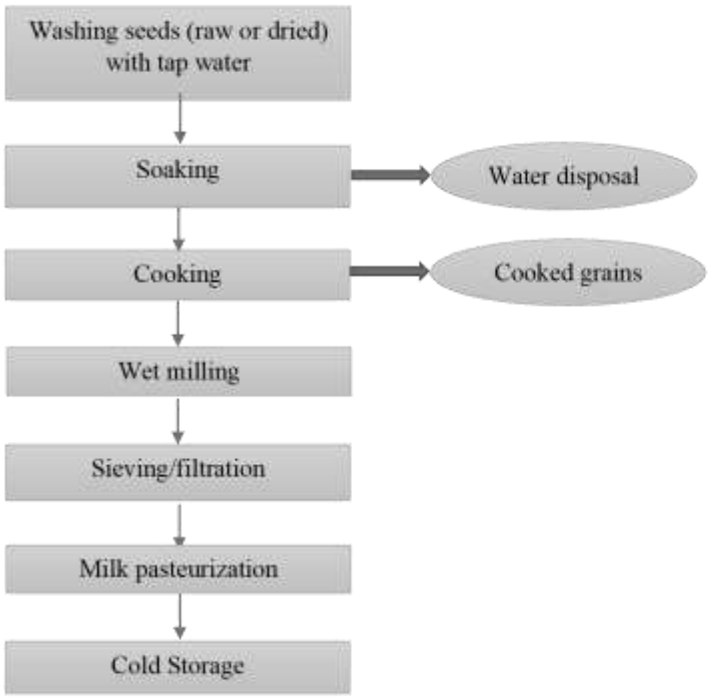

Figure 2. Chickpea milk standard extraction process

Biological, chemical aids and innovative processing

Biological and chemical aids. Undoubtedly, mechanical methods are crucial for the extraction and functionality of plant-based milk alternatives. Nevertheless, to improve the ingredient quality for flavor or fermentation purposes, chemical and biological techniques have been increasingly incorporated. Despite their potential, plant-based ingredients still present a significant challenge due to off-flavors, which remarkably restrict their application in dairy-milk-based products, particularly fermented products like cheese and yoghurt. This is particularly disagreeable because consumers are sensitive to typically 'grassy' or 'hay-like' off-flavors. To address this issue, a range of chemical and biological techniques have been strategically employed to eliminate off-flavor from the plant raw materials and enhance the functionality of other components (Pua et al., 2022).

Among the various techniques, using pH modification by adding NaOH and $NaHCO_3$ during soaking and extraction steps is recommended to enhance protein extractability under alkaline conditions, depending on the raw material. Additionally, pH adjustment is frequently used to mitigate off-flavor formation (Ma et al., 2022).

Incorporating alcohol is another recommended approach. In their studies, Ma et al. (2022) and Pua et al. (2022) demonstrated that using alcohol in the soaking step has proven to be efficient in improving protein extractability and enhancing the flavor, odor, and taste of pea yoghurt. Since these chemical methods are remarkably potent in removing odorants from the raw material, it is mandatory to reintroduce the product's aroma through alternative ingredients or fermentation strategies.

Enzymatic treatments. The variety of commercial food-grade enzymes has significantly improved the quality of plant-based ingredients. Hence, the selection of enzymes for use in plant-based dairy analogues revolves around their aptitude for breaking down macromolecules such as proteins and polysaccharides. This process helps to reduce particle size, improve solubility, and create a smoother, more palatable product. Moreover, the hydrolysis of these molecules can impart sweetness to plant-based dairy alternatives, which is a desirable quality attribute for a wide range of consumers. (Lindahl, Ahlden, Oste & Sjoholm, 1997; Mäkinen et al., 2015). In the study by Zhang et al. (2022), it was found that enzymatic hydrolysis significantly impacts the volatile flavor components of chickpea milk. Consequently, enzymatic treatment is particularly beneficial when combined with the fermentation process to enhance the organoleptic characteristics of the final product.

Germination and sprouting. As Lopes et al. (2020) have mentioned in their work, the chickpea beverage produced from sprouted seeds did not gel due to starch breakdown during seeds' germination. Based on these findings, the germination process, considered non-chemical and non-thermal processing, is an effective way to reduce the oligosaccharide content and increase the protein bioavailability. Furthermore, seed sprouting contributes to the reduction of antinutritional factors such as phytic acid leading to a decrease in the bitterness and the beany flavor of the grains. This, in turn, enhances the nutritional profile of the legume-based beverage.

Innovative processing. Although thermal and chemical treatments are essential for ensuring the textural and microbiological qualities of plant-based alternative milks, these products contain macronutrients that present challenges such as protein aggregates, oil droplets, and polysaccharides. These challenges manifest in issues like shelf life, emulsion stability, nutritional completeness, and sensory acceptability. Specifically, these factors make the dairy alternatives particularly prone to sedimentation, creaming, or syneresis during storage, which can impede their suitability as ingredients in plant-based analogues. Hence, new and advanced non-thermal processing technologies such as ultra-high-pressure homogenization and pulsed electric field processing are being explored to address the mentioned issues (Zamora & Guamis, 2015; Silva et al., 2020; Cichońska & Ziarno, 2022).

High pressure homogenization (HPH) and ultra-HPH (UHPH). These techniques have a pivotal role in preserving product stability. This is achieved by reducing the size of the dispersed phase particles (aggregate and lipid droplets) to avoid different phenomena like coalescence and skimming (Hassan, Aly & El-Hadidie, 2012; Maghsoudlou, Aalami, Mashkour & Shahraki, 2016; Malaki Nik, Tosh, Poysa, Woodroe & Corredig, 2008). The UHPH not only homogenizes the fluid but also reaches inactivation levels of sterilization which usually requires separate processes in the food industry, involving both a conventional homogenizer and a pasteurizer.

Zamora and Guamis (2015) and Silva et al. (2020) have mentioned in their studies that the UHPH technology is derived from the same principle as conventional and high-pressure homogenization (HPH) processes commonly employed in the food industry. In UHPH, pressure ranging from 100 to 400 MPa is applied, causing the liquid to flow through a high-pressure valve. This results in an increase in flow velocity, accompanied by a decrease in pressure, leading to cavitation, the chisel effect, turbulence, and collision of dispersed particles like fat droplets. Furthermore, various equipment utilizing HPH technology is available, with the maximum pressure level depending on the design and characteristics of each machine, usually ranging from 100 to 200 MPa. In contrast, classical homogenization operates at lower pressures, typically ranging from 18 to 60 MPa. The application of the HPH method in the production of plant-based milks has resulted in a remarkable improvement in flavor, and water holding capacity, as well as the formation of stable emulsions with viscosities and mouthfeel akin to those of cow's milk. An illustration of this improvement can be found in the study of Ferragut, Cruz, Trujillo, Guamis and Capellas (2009), who demonstrated that UHPH treatment (200–300 MPa) of soymilk yielded better textures compared to soymilk subjected to traditional thermal processing. The plant-based industry is challenged to maintain the quality and safety of its products. Accordingly, the most commonly used methods are pasteurization and ultra-high temperature (UHT) treatment, based on heat processsing. Their primary effect on plant-based milk macronutrients (proteins, vitamins, lipids) and quality attributes leads to undesirable changes in nutritional, sensory, chemical and physical characteristics, alongside enzymes' and microorganisms' inactivation (Aydar, Tutuncu & Ozcelik, 2020).The heating of plant milk (up to 130 °C) causes an increase in viscosity due to the interaction between non-polar amino acids and water, which increases hydrophobicity. Consequently, this leads to enhanced protein-protein interactions that can ultimately lead to sedimentation or gelling as discussed by Mäkinen et al. (2015). In addition, the use of heat treatments causes high starch concentrations, requiring the incorporation of non-thermal processing technologies to extend the shelf life of these types of plant-based milk substitutes, as emphasized by (Sethi et al., 2016). Alternative methods such as microwave heating, Ohmic heating, ultraviolet sterilization (UV-C), pulsed electric field (PEF), ultrasound (US) and high hydrostatic pressure (HHP), can be employed as substitutes for traditional thermal treatments (Table 2). To preserve the sensory and nutritional properties while extending the shelf life of plant-based milk substitutes, non-thermal technologies are more advantageous than thermal methods. Interestingly, limited research is available in the scientific literature regarding the application of these innovative approaches in the context of chickpea beverages. The optimal settings for these techniques can vary between different products, resulting in varying levels of effectiveness and outcomes. The application of pressure, temperature, and time affects sensory attributes, pH values, stability, protein solubility, and water-holding capacity of proteins. For instance, in certain studies, the reduction of total bacterial count by HHP treatment required up to 4 days (Smith, Mendonca & Jung, 2009), whereas psychotropic bacteria were inactivated at 75 °C with a pressure higher than 500 MPa, regardless of the duration of dwell time (1 to 5 min).

The effect of processing on the sensory properties of chickpea milk

Consumer's decisions regarding the purchase of functional beverages are greatly affected by factors such as suitability and accessibility. However, these products frequently face difficulties in mimicking the sensory characterristics of conventional dairy items, mainly due to undesirable off-flavors and textures. These challenges are primarily associated with lipid content, the degradation of polyunsaturated fatty acids, and the presence of anti-nutritional compounds like phytic acid and tannins (Pua et al., 2022). In legume-based dairy alternatives, the flavor profile is influenced by compounds like hexanal and pelargonic aldehyde, which contribute to undesirable 'beany' notes.

Table 2.
Thermal and non-thermal innovative technologies applied in plant-based milk processing

Technology	Mechanism	Effect	Reference
	Thermal application		
Microwave heating	The product is affected volumetrically by electromagnetic radiation within the frequency range of 103 to 104 MHz, specifically targeting the dipole of water molecules. This radiation enhances the intermolecular friction within the system by attracting and repelling the water molecules dipoles, resulting in the release of heat. Hence, the cell walls are disrupted, leading to a sudden release of cellular components into the surrounding solvent.	- Increasing product's shelf life along with reducing microbial load; - Increase in protein's digestibility, solubility; - Preservation of the organoleptic quality by preserving the molecular bonds of carbohydrates, proteins, lipids, and vitamins of the product.	Silva et al. (2020); Reyes-Jurado et al. (2021)
Ohmic heating	Upon the application of an electrical current with a frequency of 50 to 60 Hz to the matrix, a release of heat is observed due to the reorganization of ions and the increased degree of molecular agitation. Consequently, this rise in food temperature is achieved through uniform heating that does not cause mechanical damage to the product.	- 5–15 min of ohmic treatment reduced chymotrypsin inhibitor activity by 20% to 47%; - A minor rise in the protein aggregate formation; - A remarkable trypsin and chymotrypsin inhibitor (TIA, CIA) inactivation; - Sustainable technology with low maintenance cost; - Decrease the microbial load.	Aydar et al., (2020); Wattanayon, Udompijitkul & Kamonpatana, (2021)
	Non-thermal applications		
Ultraviolet sterilization (UV-C)	Non-ionizing invisible light with a wavelength of 100 to 400 nm, falling within the electromagnetic spectrum between visible light and X-rays. The beverage is exposed to UV irradiation, the liquid is penetrated and the bacterial cells are exposed.	- Reduction of bacteria resistant to conventional thermal treatment; - Improving product shelf life and psychotropic reduction in refrigerated milk stored for prolonged periods.	Makarapong et al. (2022); Silva et al. (2020)
Pulsed electric field (PEF)	The product is exposed to high voltage short pulses between two electrodes in a short time (milliseconds and even microseconds), pulse intensities (18, 20 and 22 to 80 KV/cm), number of pulses (25, 50, 75 and 100), pulse frequency of 0.5 Hz at 26 °C. Makes a good method for food products' pasteurization.	- Decrease in lipoxygenase content; - Help in reducing the particles size which increase the stability of the product, therefore, the sensory acceptability and its shelf life extending; - A very remarkable inactivation of microbial activities like *E. coli* and *S. aureus* simultaneously with the electric potential and the treatment time; - Inhibition of peroxidase activity.	Munekata et al. (2020); Pua et al. (2022); Reyes-Jurado et al. (2021); Silva et al. (2020)

Table 2. Continued

Technology	Mechanism	Effect	Reference
Ultrasound (US)	A sound wave propagates in a liquid with a frequency of 20 KHz and 100 KHz. The effectiveness of the US in inactivating microorganisms is attributed to two key mechanisms: cavitation and sonolysis (or sonoporation). Cavitation involves the formation of bubbles that expand and eventually collapse, leading to the creation of soke regions localized with high temperature (around 5500 °C) and pressure up to 50 MPa. The primary target of cavitation is the cellular membrane of the microorganisms, and the six distinct modes associated with cavitation are referred to as sonoporation.	- Reduction in viscosity and particle size leading to a better stability of the product (smaller oil droplets results in a decreased creaming index); - Reduction in the growth rate of *E. coli*, the sound waves have caused disruption of the cell membranes exposing their genetic material; - The ultrasound powers (26-104 W), processing times (2-8 min), and pulses (2-6 s) were assessed in the activation of microorganisms in almond milk; - The high intensity ultrasound guarantees high retention of bioactive compounds comparing to a thermal process.	Iorio et al. (2019); Bocker and Silva, (2022); Silva et al. (2020); Aydar et al. (2020)
High hydrostatic pressure (HHP)	The process involves applying pressure within the range of 100 to 1000 MPa, carried out in batches. Moreover, isostatic transmission applies high pressure to food in volumetric, instantaneous, and uniform manner	- A significant impact on protein functionality inducing gelation in the plant-based products such as yogurt. Nonetheless, it may cause the generation of neo-allergenic compounds in foods; - A single study has demonstrated that subjecting pollen related foods to HHP at 300-600 MPa for 5 min resulted in a reported decrease the allergenicity; - Increase water holding capacity and reduce syneresis; - Inactivate the enzymes that contribute in lipids exudation such as lipoxygenase; - The high pressure inactivates the pathogenic microorganisms; - Induce changes in sensorial properties like color and flavor; - Increase in plant-based milks stability and homogeneity by reducing their colloidal particles' size.	Aydar et al. (2020)

For chickpea milk, sensory attributes are significantly affected by its composition, particularly proteins and anti-nutritional factors, which are the key reasons causing consumer aversion. Sensory assessments from various studies (Skrzypczak et al., 2019; Lopes et al., 2020; Vallath et al., 2021) consistently reveal low ratings for aroma, mouthfeel, and aftertaste due to the beany flavor. In addition, chickpea milk has a darker hue compared to cow's milk with a chroma value of 26.07, indicating high intensity and purity (Rincon et al., 2020). Furthermore, its gritty mouthfeel, resulting from the presence of okara (the pulp residue from the milling process), further diminishes its sensory appeal.

Nevertheless, multiple studies have shown enhancements in the sensory quality of chickpea milk through processing alterations. For instance, germination and dehulling of cooked seeds have been found to improve flavor, taste, and texture (Lopes et al., 2020), while soaking and cooking chickpea seeds have been effective in reducing unpleasant volatile compounds (Duarte et al., 2022; Mefleh, Pasqualone, Caponio & Faccia, 2022). Enzymatic treatments, such as those applying papain, have also proven effective in reducing off-flavors by altering odor-related compounds (Zhang et al., 2022).

Flavoring and additive techniques have also been explored. The addition of chocolate powder, sugar (Vallath et al., 2021), or vanillin sugar (Skrzypczak et al., 2019) has effectively masked beany flavors, enhancing overall acceptability by improving aftertaste and mouthfeel. Flavoring has also been noted to boost both taste and color attributes (Rincon et al., 2020), making such strategies a promising avenue for enhancing consumer perception of chickpea milk.

CONCLUSION

The rise in dairy products consumption has brought to light varied issues, such as lactose intolerance, digestive problems and allergies. As a result, there is a growing demand for healthier, readily available, accessible, and allergen-free alternatives to dairy products. Plant-based milk options, particularly those derived from legumes, have gained substantial popularity due to their well-balanced nutritional profile and prominent content of proteins, vitamins, and minerals. This review offers a thorough investigation of chickpea milk as a plant-based alternative to cow's milk. It explores its nutritional composition, health benefits, various processing methods, and bioavailability. Among legumes, chick-peas are an excellent source of proteins, minerals, carbohydrates (mono-, di-, and oligosaccharides), and dietary fibers.

Chickpea milk stands out for its notably high protein content, which enhances its bioavailability. Although it is fat-free, it predominantly contains polyunsaturated fatty acids. Furthermore, compared to other plant-based milks, chickpea milk outranks for its high carbohydrate content, with starch being the dominant oligosaccharide. Additionally, chickpea milk is a significant source of major elements such as calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), and sodium (Na), as well as trace elements like iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn). Limited studies have investigated the bioactive compounds in chickpea milk. However, phytochemicals and antioxidant compounds, in addition to bioactive polypeptides, still maintain their bioactivity despite undergoing an extraction process and being subjected to digestive conditions. This bioactivity is represented through their anti-inflammatory, anticancer properties, and prevention of atherosclerosis and osteoporosis.

The techno-functional characteristics of chickpea proteins play a crucial role in defining the functional properties of chickpea milk. Specifically, the solubility of chickpea proteins peaks within the pH range of 8 to 10. However, the high carbohydrate content somewhat diminishes the water-holding capacity, while the oil-holding capacity of chickpea proteins is notably higher.

Chickpea milk offers health and functional benefits, as previously mentioned. Its extraction process involves both thermal and physical methods, such as cooking, milling, and sieving. To address the challenges of large-scale production of plant-based beverages, it is advantageous to explore advanced food processing technologies. These include non-thermal techniques like pulsed electric field, high-pressure homogenization, and high-hydrostatic-pressure homogenization, as well as thermal methods such as ohmic and microwave heating technologies. These techniques are crucial in enhancing the shelf life, physicochemical stability, sensory properties, and nutritional balance of plant-based milks. However, further research is needed to investigate the impact of these methods on chickpea milk and determine their effectiveness in preventing quality deterioration. Additionally, researchers should explore the properties of Algerian chickpea milk and its potential as a viable alternative to traditional cow's milk, particularly in terms of nutrition.

AUTHOR CONTRIBUTIONS

Authors' Contribution: Conceptualization, data curation, investigation, methodology, writing - original draft, A.H; Data curation, review and editing, methodology, supervision, validation, F.B; review and editing, L.D.A.

DATA AVAILABILITY STATEMENT

Data contained within the article.

AKNOWLEDGMENTS

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article. This article does not contain any studies with human or animal participants.

CONFLICT OF INTEREST

The authors declare no conflict of interest. The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

Al-Ani, I. I. M. (2020). Producing drink like grafted milk from chickpeas and evaluation of its qualitative properties. *International Journal of Drug Delivery Technology*, *10*(3), 374–377. https://doi.org/10.25258/ijddt.10.3.12

Atwaa, E. H., Ahdab, A., Elmaadawy, A., & Awaad, E. A. (2019). Production of fruit flavored probiotic rice milk beverage. *Journal of Food and Dairy Sciences*, *10*(2), 453–458. https://doi.org/10.21608/jfds.2019.71360

Aydar, E. F., Tutuncu, S., & Ozcelik, B. (2020). Plant-based milk substitutes: Bioactive compounds, conventional and novel processes, bioavailability studies, and health effects. *Journal of Functional Foods*, *70*(December 2019), 103975. https://doi.org/10.1016/j.jff.2020.103975

Bessada, S. M. F., Barreira, J. C. M., & Oliveira, M. B. P. P. (2019). Pulses and food security: Dietary protein, digestibility, bioactive and functional properties. *Trends in Food Science & Technology*, *93*, 53–68. https://doi.org/10.1016/j.tifs.2019.08.022

Bocker, R., & Silva, E. K. (2022). Innovative technologies for manufacturing plant-based non-dairy alternative milk and their impact on nutritional, sensory and safety aspects. *Future Foods*, *5*, 100098. https://doi.org/10.1016/j.fufo.2021.100098

Boye, J. I., Aksay, S., Roufik, S., Ribéreau, S., Mondor, M., Farnworth, E., & Rajamohamed, S. H. (2010). Comparison of the functional properties of pea, chickpea and lentil protein concentrates processed using ultrafiltration and isoelectric precipitation techniques. *Food Research International*, *43*(2), 537–546. https://doi.org/10.1016/j.foodres.2009.07.021

Brusati, M., Baroni, L., Rizzo, G., Giampieri, F., & Battino, M. (2023). Plant-based milk alternatives in child nutrition. *Foods*, *12*(7), Article 7. https://doi.org/10.3390/foods12071544

Champ, M. M.-J. (2002). Non-nutrient bioactive substances of pulses. *British Journal of Nutrition*, *88*(S3), 307–319. https://doi.org/10.1079/BJN2002721

Cichońska, P., & Ziarno, M. (2022). Legumes and legume-based beverages fermented with lactic acid bacteria as a potential carrier of probiotics and prebiotics. *Microorganisms*, *10*(1), 91. https://doi.org/10.3390/microorganisms10010091

Collard, K. M., & McCormick, D. P. (2021). A nutritional comparison of cow’s milk and alternative milk products. *Academic Pediatrics*, *21*(6), 1067–1069. https://doi.org/10.1016/j.acap.2020.12.007

Duarte, C. M., Mota, J., Assunção, R., Martins, C., Ribeiro, A. C., Lima, A., Raymundo, A., Nunes, M. C., Ferreira, R. B., & Sousa, I. (2022a). New alternatives to milk from pulses: chickpea and lupin beverages with improved digestibility and potential bioactivities for human health. *Frontiers in Nutrition*, *9*(July 2022), 1–12. https://doi.org/10.3389/fnut.2022.852907

Duarte, C. M., Mota, J., Assunção, R., Martins, C., Ribeiro, A. C., Lima, A., Raymundo, A., Nunes, M. C., Ferreira, R. B., & Sousa, I. (2022b). New alternatives to milk from pulses: chickpea and lupin beverages with improved digestibility and potential bioactivities for human health. *Frontiers in Nutrition*, *9*, 852907. https://doi.org/10.3389/fnut.2022.852907

Duarte, C. M., Nunes, M. C., Gojard, P., Dias, C., Ferreira, J., Prista, C., Noronha, P., & Sousa, I. (2022). Use of European pulses to produce functional beverages – From chickpea and lupin as dairy alternatives. *Journal of Functional Foods*, *98*(June). https://doi.org/10.1016/j.jff.2022.105287

Ferragut, V., Cruz, N. S., Trujillo, A., Guamis, B., & Capellas, M. (2009). Physical characteristics during storage of soy yogurt made from ultra-high pressure homogenized soymilk. *Journal of Food Engineering*, *92*(1), 63–69. https://doi.org/10.1016/j.jfoodeng.2008.10.026

Fu, Y. H., & Zhang, F. C. (2013). Changes in isoflavone glucoside and aglycone contents of chickpea yoghurt during fermentation by *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. *Journal of Food Processing and Preservation*, *37*(5), 744–750. https://doi.org/10.1111/j.1745-4549.2012.00713.x

Ghribi, A. M., Gafsi, I. M., Blecker, C., Danthine, S., Attia, H., & Besbes, S. (2015). Effect of drying methods on physico-chemical and functional properties of chickpea protein concentrates. *Journal of Food Engineering*, *165*, 179–188. https://doi.org/10.1016/j.jfoodeng.2015.06.021

Gobbi, L., Ciano, S., Rapa, M., & Ruggieri, R. (2019). Biogenic amines determination in "plant milks." *Beverages*, *5*(2), Article 2. https://doi.org/10.3390/beverages5020040

Grasso, N., Lynch, N. L., Arendt, E. K., & O'Mahony, J. A. (2022). Chickpea protein ingredients: A review of composition, functionality, and applications. *Comprehensive Reviews in Food Science and Food Safety*, *21*(1), 435–452. https://doi.org/10.1111/1541-4337.12878

Gupta, S., & Bisla, G. (2019). Nutritional and sensory characteristics of oat milk based yoghurt. *International Journal of Applied Home Science*, *6 (6-8)*, 261–265. https://doi.org/10.36537/IJAHS/6.6-8/261-265

Guzmán, T. J., Martínez-Ayala, A. L., García-López, P. M., Soto-Luna, I. C., & Gurrola-Díaz, C. M. (2021). Effect of the acute and chronic administration of *Lupinus albus* β-conglutin on glycaemia, circulating cholesterol, and genes potentially involved. *Biomedicine & Pharmacotherapy*, *133*, 110969. https://doi.org/10.1016/j.biopha.2020.110969

Hassan, A. A., Aly, M. M. A., & El-Hadidie, S. T. (2012). Production of cereal-based probiotic beverages. *World Applied Sciences Journal*, *19*, 1367–1380. https://doi.org/10.5829/idosi.wasj.2012.19.10.2797

Iorio, M. C., Bevilacqua, A., Corbo, M. R., Campaniello, D., Sinigaglia, M., & Altieri, C. (2019). A case study on the use of ultrasound for the inhibition of *Escherichia coli* O157:H7 and *Listeria monocytogenes* in almond milk. *Ultrasonics Sonochemistry*, *52*, 477–483. https://doi.org/10.1016/j.ultsonch.2018.12.026

Jarpa-Parra, M. (2017). Lentil protein: A review of functional properties and food application. An overview of lentil protein functionality. *International Journal of Food Science & Technology*, *53*(4), 892-903. https://doi.org/10.1111/ijfs.13685

Jukanti, A. K., Gaur, P. M., Gowda, C. L. L., & Chibbar, R. N. (2012). Nutritional quality and health benefits of chickpea (*Cicer arietinum* L.): A review. *The British Journal of Nutrition*, *108 Suppl 1*, S11-26. https://doi.org/10.1017/S0007114512000797

Kamboj, R., & Nanda, V. (2017). Proximate composition, nutritional profile and health benefits of legumes – A review. *Legume Research, 41*(3), 325-332. https://doi.org/10.18805/LR-3748

Kameník, J., Saláková, A., Vyskočilová, V., Pechová, A., & Haruštiaková, D. (2017). Salt, sodium chloride or sodium? Content and relationship with chemical, instrumental and sensory attributes in cooked meat products. *Meat Science*, *131*, 196–202. https://doi.org/10.1016/j.meatsci.2017.05.010

Kaur, M., & Singh, N. (2007). Characterization of protein isolates from different Indian chickpea *(Cicer arietinum* L.*)* cultivars. *Food Chemistry*, *102*(1), 366–374. https://doi.org/10.1016/j.foodchem.2006.05.029

Kaur, R., & Prasad, K. (2021). Technological, processing and nutritional aspects of chickpea *(Cicer arietinum)*–A review. *Trends in Food Science and Technology*, *109*(September 2020), 448–463. https://doi.org/10.1016/j.tifs.2021.01.044

Kishor, K., David, J., Tiwari, S., Singh, A., & Rai, B. (2017). Nutritional composition of chickpea (*Cicer arietinum*) milk. *International Journal of Chemical Studies*, *5*(4), 1941-1944.

Kundu, P., Dhankhar, J., & Sharma, A. (2018). Development of non-dairy milk alternative using soymilk and almond milk. *Current Research in Nutrition and Food Science*, *6*(1), 203–210. https://doi.org/10.12944/CRNFSJ.6.1.23

Lindahl, L., Ahlden, I., Oste, R., & Sjoholm, I. (1997). *Homogeneous and stable cereal suspension and a method of making the same* (United States Patent US5686123A). https://patents.google.com/patent/US5686123A/en

Lopes, M., Pierrepont, C., Duarte, C. M., Filipe, A., Medronho, B., & Sousa, I. (2020). Legume beverages from chickpea and lupin, as new milk alternatives. *Foods*, *9*(10), Article 10. https://doi.org/10.3390/foods9101458

López-Martínez, L. X., Leyva-López, N., Gutiérrez-Grijalva, E. P., & Heredia, J. B. (2017). Effect of cooking and germination on bioactive compounds in pulses and their health benefits. *Journal of Functional Foods*, *38*, 624–634. https://doi.org/10.1016/j.jff.2017.03.002

Ma, K. K., Greis, M., Lu, J., Nolden, A. A., McClements, D. J., & Kinchla, A. J. (2022). Functional performance of plant proteins. *Foods*, *11*(4), Article 4. https://doi.org/10.3390/foods11040594

Maghsoudlou, Y., Aalami, M., Mashkour, M., & Shahraki, M. (2016). Optimization of ultrasound-assisted stabilization and formulation of almond milk. *Journal of Food Processing and Preservation*, *40*, 828–839. https://doi.org/10.1111/jfpp.12661

Makarapong, D., Tantayanon, S., Gowanit, C., Jareonsawat, J., Samngamnim, S., Wataradee, S., Hogeveen, H., & Inchaisri, C. (2022). Use of UV-C irradiation as pretreatment for controlling the number of microorganisms in raw milk after milking. Retrieved from SSRN: https://ssrn.com/abstract=4097513 or http://dx.doi.org/10.2139/ssrn.4097513

Makinde, F., & Adebile, T. (2018). Influence of processing treatments on quality of vegetable milk from almond *(Terminalia catappa)* kernels. *Acta Scientific Nutritional Health*, *2*(6), 37-42. https://actascientific.com/ASNH/pdf/ASNH-02-0090.pdf

Mäkinen, O. E., Wanhalinna, V., Zannini, E., & Arendt, E. K. (2015). Foods for special dietary needs: non-dairy plant-based milk substitutes and fermented dairy-type products. *56*(3), 339–349. https://doi.org/10.1080/10408398.2012.761950

Malaki Nik, A., Tosh, S., Poysa, V., Woodrow, L., & Corredig, M. (2008). Physicochemical characterization of soymilk after step-wise centrifugation. *Food Research International*, *41*(3), 286–294. https://doi.org/10.1016/j.foodres.2007.12.005

Manzoor, M., Manzoor, A., Siddique, R., & Ahmad, N. (2017). Nutritional and sensory properties of cashew seed *(Anacardium occidentale)* Milk. *Modern Concepts & Developments in Agronomy*, *1*(1). MCDA.000501. 2017. https://doi.org/10.31031/MCDA.2017.01.000501

Mefleh, M., Pasqualone, A., Caponio, F., & Faccia, M. (2022). Legumes as basic ingredients in the production of dairy-free cheese alternatives: A review. *Journal of the Science of Food and Agriculture*, *102*(1), Article 1. https://doi.org/10.1002/jsfa.11502

Mendly-Zambo, Z., Powell, L. J., & Newman, L. L. (2021). Dairy 3.0: Cellular agriculture and the future of milk. *Food, Culture & Society*, *24*(5), Article 5. https://doi.org/10.1080/15528014.2021.1888411

Miao, M., Zhang, T., & Jiang, B. (2009). Characterisations of kabuli and desi chickpea starches cultivated in China. *Food Chemistry*, *113*(4), 1025–1032. https://doi.org/10.1016/j.foodchem.2008.08.056

Mohamed, M., Legesse, Y., & Abdimahad, K. (2023). Handling, processing and composition of cow milk under two traditional farming systems in kebribeyah district of fafan zone, Somali regional state, Ethiopia. *American Journal of Aquaculture and Animal Science*, *2*, 1–6. https://doi.org/10.54536/ajaas.v2i1.1024

Moreno-Valdespino, C. A., Luna-Vital, D., Camacho-Ruiz, R. M., & Mojica, L. (2020). Bioactive proteins and phytochemicals from legumes: Mechanisms of action preventing obesity and type-2 diabetes. *Food Research International (Ottawa, Ont.), 130*, 108905. https://doi.org/10.1016/j.foodres.2019.108905

Mota, J., Direito, R., Rocha, J., Fernandes, J., Sepodes, B., Figueira, M. E., Raymundo, A., Lima, A., & Ferreira, R. B. (2021). Lupinus albus protein components inhibit MMP-2 and MMP-9 gelatinolytic activity in *vitro* and in *vivo*. *International Journal of Molecular Sciences*, *22*(24), Article 24. https://doi.org/10.3390/ijms222413286

Mudryj, A. N., Yu, N., & Aukema, H. M. (2014). Nutritional and health benefits of pulses. *Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquee, Nutrition Et Metabolisme*, *39*(11), 1197–1204. https://doi.org/10.1139/apnm-2013-0557

Munekata, P. E. S., Domínguez, R., Budaraju, S., Roselló-Soto, E., Barba, F. J., Mallikarjunan, K., Roohinejad, S., & Lorenzo, J. M. (2020). Effect of innovative food processing technologies on the physicochemical and nutritional properties and quality of non-dairy plant-based beverages. *Foods*, *9*(3), 1–16. https://doi.org/10.3390/foods9030288

Ning, S., Mainvil, L.A., Thomson, R.K & McLean, R.M. (2017). Dietary sodium reduction in New Zealand: Influence of the Tick label. *Asia Pacific Journal of Clinical Nutrition*, *26*(6). https://doi.org/10.6133/apjcn.032017.06

Onder, S., Can Karaca, A., Ozcelik, B., Alamri, A. S., Ibrahim, S. A., & Galanakis, C. M. (2023). Exploring the amino-acid composition, secondary structure, and physicochemical and functional properties of chickpea protein isolates. *ACS Omega*, *8*(1), 1486–1495. https://doi.org/10.1021/acsomega.2c06912

Ouazib, M., Moussou, N., Oomah, B., Zaidi, F., & Wanasundara, J. (2015). Effect of processing and germination on nutritional parameters and functional properties of chickpea *(Cicer arietinum* L.*)* from Algeria. *Journal of Food Legumes*, *28*(2), 35–42.

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. https://doi.org/10.1080/10408398.2019.1674243

Pua, A., Tang, V. C. Y., Goh, R. M. V., Sun, J., Lassabliere, B., & Liu, S. Q. (2022). Ingredients, processing, and fermentation: addressing the organoleptic boundaries of plant-based dairy analogues. *Foods*, *11*(6), Article 6. https://doi.org/10.3390/foods11060875

Reyes-Jurado, F., Soto-Reyes, N., Dávila-Rodríguez, M., Lorenzo-Leal, A. C., Jiménez-Munguía, M. T., Mani-López, E., & López-Malo, A. (2021). Plant-based milk alternatives: types, processes, benefits, and characteristics. *Food Reviews International*, *39*(4), 2320-2351. https://doi.org/10.1080/87559129.2021.1952421

Rincon, L., Braz Assunção Botelho, R., & de Alencar, E. R. (2020). Development of novel plant-based milk based on chickpea and coconut. *LWT*, *128*, 109479. https://doi.org/10.1016/j.lwt.2020.109479

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

Sasi, M., Kumar, S., Hasan, M., S R, A., Garcia-Gutierrez, E., Kumari, S., Prakash, O., Nain, L., Sachdev, A., & Dahuja, A. (2022). Current trends in the development of soy-based foods containing probiotics and paving the path for soy-synbiotics. *Critical Reviews in Food Science and Nutrition*, *63*(29), 9995-10013. https://doi.org/10.1080/10408398.2022.2078272

Sethi, S., Tyagi, S. K., & Anurag, R. 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

Silva, A. R. A., Silva, M. M. N., & Ribeiro, B. D. (2020). Health issues and technological aspects of plant-based alternative milk. *Food Research International*, *131*(June 2019), 108972. https://doi.org/10.1016/j.foodres.2019.108972

Skrzypczak, K., Jabłońska-Ryś, E., Gustaw, K., Sławińska, A., Waśko, A., Radzki, W., Michalak-Majewska, M., & Gustaw, W. (2019). Reinforcement of the antioxidative properties of chickpea beverages through fermentation carried out by probiotic strain lactobacillus plantarum 299v. *Journal of Pure and Applied Microbiology*, *13*(1), 1–12. https://doi.org/10.22207/JPAM.13.1.01

Smith, K., Mendonca, A., & Jung, S. (2009). Impact of high-pressure processing on microbial shelf-life and protein stability of refrigerated soymilk. *Food Microbiology*, *26*(8), 794–800. https://doi.org/10.1016/j.fm.2009.05.001

Tontul, İ., Kasimoglu, Z., Asik, S., Atbakan, T., & Topuz, A. (2018). Functional properties of chickpea protein isolates dried by refractance window drying. *International Journal of Biological Macromolecules*, *109*, 1253–1259. https://doi.org/10.1016/j.ijbiomac.2017.11.135

Vallath, A., & Shanmugam, A. (2022). Study on model plant based functional beverage emulsion (non-dairy) using ultrasound—A physicochemical and functional characterization. *Ultrasonics Sonochemistry*, *88*, 106070. https://doi.org/10.1016/j.ultsonch.2022.106070

Vanga, S. K., & Raghavan, V. (2018). How well do plant based alternatives fare nutritionally compared to cow's milk? *Journal of Food Science and Technology*, *55*(1), 10–20. https://doi.org/10.1007/s13197-017-2915-y

Wang, S., Chelikani, V., & Serventi, L. (2018). Evaluation of chickpea as alternative to soy in plant-based beverages, fresh and fermented. *LWT*, *97*, 570–572. https://doi.org/10.1016/j.lwt.2018.07.067

Wattanayon, W., Udompijitkul, P., & Kamonpatana, P. (2021). Ohmic heating of a solid-liquid food mixture in an electrically conductive package. *Journal of Food Engineering*, *289*, 110180. https://doi.org/10.1016/j.jfoodeng.2020.110180

Withana-Gamage, T. S., Wanasundara, J. P., Pietrasik, Z., & Shand, P. J. (2011). Physicochemical, thermal and functional characterisation of protein isolates from Kabuli and Desi chickpea *(Cicer arietinum* L.*):* A comparative study with soy (*Glycine max*) and pea (*Pisum sativum* L.). *Journal of the Science of Food and Agriculture*, *91*(6), 1022–1031. https://doi.org/10.1002/jsfa.4277

Yadav, S. S., Redden, R.J., Chen, W., & Sharma, B. (Eds.). (2007). *Chickpea breeding and management*. CABI. https://www.cabidigitallibrary.org/doi/book/10.1079/9781845932138.000

Zaheer, K., & Humayoun Akhtar, M. (2017). An updated review of dietary isoflavones: Nutrition, processing, bioavailability and impacts on human health. *Critical Reviews in Food Science and Nutrition*, *57*(6), 1280–1293. https://doi.org/10.1080/10408398.2014.989958

Zamora, A., & Guamis, B. (2015). Opportunities for Ultra-High-Pressure Homogenisation (UHPH) for the food industry. *Food Engineering Reviews*, *7*(2), 130–142. https://doi.org/10.1007/s12393-014-9097-4

Zhang, X., Liu, S., Xie, B., & Sun, Z. (2022). An approach to processing more bioavailable chickpea milk by combining enzymolysis and probiotics fermentation. *Journal of Food Quality*, *2022*, 17–21. https://doi.org/10.1155/2022/1665524

Zhang, X., Zhang, S., Xie, B., & Sun, Z. (2021). Influence of lactic acid bacteria fermentation on physicochemical properties and antioxidant activity of chickpea yam milk. *Journal of Food Quality*, *2021*. https://doi.org/10.1155/2021/5523356

Zia-Ul-Haq, M., Iqbal, S., Ahmad, S., Imran, M., Niaz, A., & Bhanger, M. I. (2007). Nutritional and compositional study of Desi chickpea *(Cicer arietinum* L.*)* cultivars grown in Punjab, Pakistan. *Food Chemistry*, *105*(4), 1357–1363. https://doi.org/10.1016/j.foodchem.2007.05.004

MLEKO OD LEBLEBIJE: NUTRITIVNI PROFIL, FUNKCIONALNE KARAKTERISTIKE, BIOAKTIVNA JEDINJENJA I POBOLJŠANJE KVALITETA – SVEOBUHVATAN PREGLED

Aya Hamioud[*1], Farida Benmeziane[1,2], Lynda Djermoune-Arkoub[1,3]

[1]Univerzitet u Bedžaji, Fakultet prirodnih nauka, Departman za biologiju, Laboratorija za biomatematiku, biofiziku, biohemiju i scientometriju, Bedžaja, 06000, Alžir
[2]Čadli Bendžedid Univerzitet u El-Tarfu, Fakultet prirodnih nauka, Departman poljoprivrednih nauka, BP 73, El-Tarf, 36000, Alžir
[3]Univerzitet u Bedžaji, Tehnološki fakultet, Departman za procesno inženjerstvo, Bedžaja, 06000, Alžir

Sažetak: Potrošnja i proizvodnja mlečnih proizvoda je u stalnom porastu a kao posledica ovog trenda uočava se prevalencija alergija na kravlje mleko i netolerancije na laktozu. Iz ovog razloga postoji hitna potreba za alternativnim rešenjem, što je i rezultiralo brojnim istraživanjima na ovu temu u mlečnoj industriji. Biljna mleka su se pojavila kao najpopularnije i najpogodnije zamene; to su napici koji se ekstraktuju iz žitarica, pseudožitarica, mahunarki, orašastih plodova ili semenki. Mahunarke, zbog visokog sadržaja proteina, pokazale su se kao jedna od uspešnijih opcija kao sirovine za mlečne analoge. Jedna od takvih mahunarki je leblebija, koja ne samo da ima bogat sadržaj proteina, već sadrži i minerale, vlakna, nezasićene masne kiseline, bioaktivna jedinjenja i antioksidativna svojstva. Uprkos ograničenim dostupnim podacima o razvoju alternativnih napitaka na bazi leblebija, ovaj pregled se oslanja na uvide iz postojećih studija koje su istraživale mleko od leblebija obuhvatajući različite teme kao što su nutritivni sastav u poređenju s drugim biljnim zamenama za mleko, zdravstvene prednosti povezane s bioaktivnim i funkcionalnim jedinjenjima, i najnovije metode koje se koriste u ekstrakciji nemlečnih napitaka.

Ključne reči: *biljni napitak, proteini, leguminoze, bioaktivna jedinjenja, nove tehnologije prerade, funkcionalna svojstva, rok trajanja*

Received: *27 September 2024/* ***Received in revised form:*** *03 December 2024/* ***Accepted:*** *03 December 2024*

Available online: *January 2025*