A comparative evaluation of five milk-producing mammals: Benefits and safety

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Abstract: Milk is a central characteristic of the Mammalia class of animals. This study describes the properties of milk of various domestic dairy mammals (cow, buffalo-cow, doe, ewe, and camel cow). Its physical and chemical components, therapeutic benefits, allergenicity, and safety have all been examined in detail. Cow's milk remains the most globally produced type, accounting for over 80% of total milk production. Milk from ewes and cows has lower cholesterol content (8 mg/100 g) compared to milk from cows and does (10 mg/100 g). Additionally, ewe and cow's milk have higher lactose levels (4.86% and 5%) than cow and doe milk (4.76% and 4.20%). Doe milk is known for its higher fat content, typically ranging from 3.4% to 4.2%. On the other hand, camel milk contains significant antioxidants that can protect human cells from oxidative damage. The ingestion of milk from cows or buffalos-cow milk may induce minor allergic reactions; however, milk can also ease some allergy problems. Ewe milk can benefit those with eczema and asthma. This study highlights the viability of different milk types, including the emergence of plant-based and cellular milk options and other commercially available milk alternatives. The dairy industry and related fields can benefit from understanding the distinctive qualities of milk from various species in a variety of scientific and real-world applications.
Keywords: Milk production, Dairy industry, Mammalia, Nutritional content and Allergenicity

1. Introduction

The domestication of animals for meat, fur, and milk dates back to the Neolithic period, when humans began adapting their lifestyles to establish settled communities (Alt et al., 2022). Milk, being an essential nutrient, a regulator of social systems, and a defining trait of mammals, is consumed by humans from various sources throughout their lives, including their mother's milk during their early years. Milk supports the growth of diverse microorganisms, encompassing lactic acid bacteria (*Lactobacillus, Streptococcus,* and *Leuconostoc)* (Obioha et al., 2021), pathogenic bacteria (*Salmonella, Escherichia coli, Listeria monocytogenes, Campylobacter*, and *Staphylococcus aureus*) (Schneider et al., 2021; Tareen et al., 2022), yeasts (*Candida, Kluyveromyces*, and *Saccharomyces*), and molds (*Penicillium* and *Aspergillus*). This variety increases the risk of contamination and spoilage (Awasti and Anand, 2020). The composition of milk varies among species and even between breeds of the same species, influenced by factors such as lactation stage, diet, season, water availability, and other variables (Togo et al., 2019). Milk comprises water-soluble vitamins, proteins (casein and whey), carbohydrates (lactose), fats (phospholipids, short-chain saturated fatty acids, long-chain mono- and polyunsaturated fatty acids), and mineral salts (calcium, phosphorus, iron, potassium, magnesium, selenium, etc.). The global dairy market has undergone significant transformations due to technological advancements, changing consumer preferences, shifts in production and distribution methods, and evolving market dynamics (Beber et al., 2019). Countries are expanding their agricultural practices, livestock populations, dairy-related technology and infrastructure, economic factors, and market demand.

Milk and its derivatives find applications in numerous cosmetics and medications. High quantities of calcium, phosphorus, and vitamin D in milk collectively support the formation, structure, and absorption of minerals necessary for optimal bone and tooth health. Milk reduces the production of oral acid, preventing tooth decay and cavity formation (Beber et al., 2019). It can contribute to cancer prevention and the preservation of the heart, bones, gallbladder, skin, reproductive, and digestive systems. The proteins in milk are recognized for their muscle-building and repair properties. Consuming milk after exercise aids in muscle recovery and replenishment. Its high water content and nutrient-rich composition provide energizing hydration (Drewnowski et al., 2018). Fermented forms of milk, such as yogurt, can contain beneficial probiotics that support a healthy gut microbiome, aiding in digestion and promoting overall digestive well-being. In certain medical conditions, like malnutrition, underweight, or specific nutrient deficiencies, milk can serve as a nutritional supplement, providing additional calories, proteins, and essential nutrients (Hassen et al., 2022).

The milk from different milk-producing animals offers distinct advantages. In 2018, the majority of milk (81%) was produced by cows, followed by does, ewes, camel cows, and buffaloes (15%) (Nayik et al., 2022). While cow's milk is widely available, buffalo milk is richer in fat and protein, making it ideal for dairy product production. Doe milk is easily digestible, while ewe milk is nutrient-dense and often used in specialty cheeses (Bharti et al., 2022). Camel cow milk is unique, with higher vitamin and mineral content, lower lactose and cholesterol levels, and potential therapeutic effects. Historically valued for its immune-boosting effects, donkey milk has been used to treat respiratory issues, digestive disorders, and skin conditions (Salvo et al., 2022). Reindeer milk, consumed by indigenous peoples of Northern Europe and Asia, has been associated with healing effects on various ailments and overall well-being. Mare's milk, being nutritionally rich in proteins, vitamins, minerals, and essential fatty acids, has been used as a dietary supplement for individuals with specific nutritional needs or deficiencies, including infants, convalescents, and those with weakened immune systems. Mare's milk has a lower lactose content compared to cow's milk, known for its easy digestibility and digestive health, potentially making it suitable for individuals with lactose intolerance or sensitive digestive systems (Lajnaf et al., 2023). Traditionally used for their potential immune-boosting properties, mare's milk and mare's milk-based skincare products have been proposed as remedies for skin conditions such as eczema, psoriasis, and dermatitis, given their protein- and fatty acid-rich composition that may provide soothing and moisturizing effects when applied topically. Mare's milk is a suitable alternative for those with milk-related allergies or intolerances, as it has different proteins and a distinct allergenic profile (Nie et al., 2022).

In recent times, non-dairy alternatives have exerted increasing pressure on the global dairy industry despite its expansion and transformation (Bojovic and McGregor, 2022). Modern digital technologies, including cutting-edge intelligent automated and robotic bio-machine complexes, are being introduced to the dairy industry, facilitating the development of smart dairy farms that employ advanced technology and drones to monitor animals (Drewnowski and Team, 2018). The Food and Agriculture Organization of the United Nations (FAO/UN 2020) projects an average annual increase of 2.5% in worldwide milk output (Henchion et al., 2017). In 2020, the quantity of milk produced was 906 million metric tons, an increase of 18 million metric tons (2%) from the previous year (Zhao et al., 2020). Asia (41.8%), Europe (26%), and North America (12.2%) collectively contributed to the production of 80% of the world's milk supply in 2020 (Lawrence and Lawrence, 2021). The FAO/UN forecasts that worldwide milk output will increase by 1.7% annually until 2030, reaching 1.02 billion metric tons (Mickiewicz and Volkava, 2022). Given the diversity of animals, it is essential to highlight the benefits and differences between the various types of milk. Different nations produce different species of animals for their general and subsidized milk production; therefore, it largely depends on the region. This article will focus on the differences between the various kinds of animal milk as well as their benefits and applications, including special medical, health, and cosmetic benefits.

2. Physical Variations in Different Milk Types

The physical characteristics of milk vary depending on the animal species, but it typically exhibits a white or yellowish color, a slightly sweet taste, an aromatic aroma, and a thick texture. Camel cow, ewe, and doe milk are usually yellower than cow milk, whereas doe and buffalo milk tend to be whiter. Despite having a similar pH, the differences are highlighted in Tables 1 and 2. Buffalo milk, owing to its high-fat content, is the thickest, followed by ewe's milk, while doe and camel cow milk are less viscous. Cow milk presents a grassy and pleasant taste, whereas ewe's milk has an astringent flavor. The taste of milk is influenced by its high sodium chloride (NaCl) content, resulting in a sweet and salty flavor; doe milk possesses a distinct goaty flavor and odor; and buffalo milk carries a floral scent (Table 1). In the dairy industry, thermal techniques like high-temperature-short-time (HTST) are commonly employed to heat fresh milk, extending its shelf life, albeit potentially altering the taste slightly (Escuderer et al., 2018). These techniques can also impact the physical and chemical quality of milk, leading to protein denaturation, non-enzymatic browning, and vitamin loss (Nikmaram and Keener, 2022). Tables 1 and 2 present the physical and chemical characteristics of different milk types (Dvorkin and Chernikova, 2022; Sudharani et al., 2021; Chethouna et al., 2022; Semenovich et al., 2019; Palaniyammal et al., 2019; Mohammed et al., 2020; Bekere et al., 2022).

Animals	Cow	Buffalo-cow	Doe	Ewe	Camel cow
Color	Yellow	White	White	Yellow	Opaque white
pH	6.63	6.8	6.56	6.6	6.5
Viscosity	Moderately thick	Thickest due to high-fat content	Less viscous than cow's	Next to buffalo milk in thickness	Less thick
Specific gravity mg/100ml	1.023	1.07	1.029	1.033	1.029
Flavor	Grassy, sweet	Sweet, floral	goaty	Barnyard, nutty	Sweet but salty when dehydrated

Table 1 – Comparative analysis of physical characteristics and concentrations of milk across various animal species.

Animals	Cow	Buffalo-cow	Doe	Ewe	Camel cow
Calories (cal/100g)	66	100	70	108	49
Water (%)	86	83	80.5	80.7	85
Proteins (g)	8	9	3.6	6	2.5
Casein (g)	2.46	4.0	2.81	4.18	2.21
Fats (g)	3.9	8	3.5	6	2.9- 3.7
Cholesterol (mg)	25.6	6.5	16.6	14.23	37.1
Sugar (g)	5	4.4	5.1	4.0	4.8
Minerals (ash%)	0.64	0.88	1.04	0.72	0.62

* The values are the averages from the various cited references

Table 2 – Physical-chemical components comparison: concentrations in 100g of milk across different animal species

3. Chemical Variations in Different Milk Types

Proteins, lipids, carbohydrates, minerals, and vitamins contribute to making milk a nutrient-rich food, with their composition depending on factors such as the species, season, health, hydration, developmental stage, and environment of the animal. Essential components of milk include water, fat, proteins, lactose (milk sugar), minerals (salts), trace amounts of colors, enzymes, vitamins, phospholipids, and gases, with variations observed among different animal species (Bekere et al., 2022). Notably, due to differences in genetic makeup and physiology, cow's milk exhibits a distinct nutrient profile compared to doe's milk or ewe's milk (Table 2). The dietary patterns of animals may also vary with the seasons, impacting nutrient content (Zhu et al., 2021). For instance, cows grazing on fresh pastures in the spring may produce milk with elevated levels of specific nutrients compared to cows fed hay in the winter (Méndez et al., 2023). The health, hydration, or illnesses of animals can further influence milk composition; for example, a sick cow may produce milk with reduced levels of certain nutrients, depending on the nature of the illness and the cow's circumstances (Ibrahim and Kirmani, 2021). Reduced feed intake or impaired digestion can affect the protein content, as well as certain vitamins and minerals, which may be depleted due to inadequate absorption or utilization by the cow's body during illness (Hassen, 2020).

The stage of lactation or the developmental state of the young animal also plays a role in shaping the composition of proteins, fats, vitamins, and minerals in milk (Ibrahim and Kirmani, 2021). Early lactation milk tends to have a higher protein content, providing essential amino acids for the rapid growth of young animals (Cao et al., 2021). The increased fat content in this stage serves to provide energy and higher concentrations of vitamins and minerals, such as calcium and phosphorus, crucial for bone development. As the young animal matures and requires less rapid growth, the concentrations of proteins and fats may decrease as lactation progresses. Conversely, with the growing offspring's increased energy needs, the concentration of lactose (milk sugar) may rise (Josefson et al., 2023). This study examines the inherent nutritional advantages present in diverse milk types sourced from distinct animal species. Table 2 provides a comprehensive overview of the physical and chemical composition of these milk varieties.

3.1. Milk Proteins

The two primary proteins found in milk are casein and whey protein. In bovine milk, casein constitutes approximately 80% (29.5 g/L) of the total protein, while whey protein makes up around 20% (6.3 g/L) (Sudha et al., 2022). Calcium phosphate-micelle complexes form the majority of casein, primarily being phosphate-conjugated, making milk an excellent source of phosphate. Whey, a byproduct of the coagulation process used in cheese production, comprises all milk components that remain soluble after reducing the pH of milk to 4.6 (Gamlath et al., 2020). Approximately 65% of whey protein consists of beta-lactoglobulin, alpha-lactalbumin, bovine serum albumin, and immunoglobulins (Jensen et al., 2022).

Proteins play crucial roles in various physiological processes for both humans and animals, including tissue growth and repair, enzyme production and function, hormone regulation, immune system function, and cellular transport and storage. They facilitate the transport of essential molecules such as oxygen (via hemoglobin) and lipids (via lipoproteins) (Morris and Mohiuddin, 2020). Additionally, proteins contribute to the storage and release of vital molecules like iron and oxygen in muscle cells (via myoglobin). While carbohydrates and fats serve as the primary sources of energy, proteins can be utilized as an energy source when carbohydrates and fats are insufficient. However, their primary functions lie in their structural and functional roles within the body. Adequate protein intake is essential to ensuring optimal health. Given that casein and whey proteins are the primary components of cheese, the size of casein micelles and their interaction with milk minerals directly impact cheese quality and flavor (Ravash et al., 2022).

3.1.1. Casein

Camel cow milk (77.50%) and cow milk (77.23%) have the highest casein contents, respectively. Buffalo milk contains approximately 68.93% casein, while ewe milk contains about 73.00% (Nayak et al., 2020). Among the three main types of casein—alpha (α), beta (β), and kappa (κ)—the alpha fraction exhibits polymorphism and is denoted as αs1 and αs2 casein. The αs1 fraction is prevalent in cow's and buffalo's milk, and it is a key factor in causing milk protein allergies (MPA) in humans (Hassanin et al., 2022). MPA involves an allergic reaction to proteins commonly found in cow's milk, wherein the body's immune system overreacts to proteins recognized as a threat. It has been reported that approximately 20 types of proteins in cow's milk can trigger cow's MPA (Baghlaf and Eid, 2021). αs1 casein is nearly absent in some species due to mutations in the genes responsible for its expression (Osthoff et al., 2020).

Similar to humans, animals can also experience allergic reactions to proteins in milk. When calves or other species consume cow's milk, their immune systems may overreact, mistakenly interpreting the milk proteins as foreign substances. Reactions can manifest as gastrointestinal issues (diarrhea, vomiting), skin problems (itching, rashes), respiratory issues (coughing, wheezing), and even more severe systemic reactions. Some species may be less prone to allergic reactions due to the absence or lower levels of certain milk proteins, such as αs1 casein, a common allergen in cow's milk (El-Shafie et al., 2023). In cases where MPA is suspected, proper diagnosis, management, and potential dietary changes are essential.

3.1.2. Whey Proteins

Whey protein, a significant component of milk, is primarily composed of α-lactalbumin and β-lactoglobulin. α-Lactalbumin is a crucial protein in lactose synthesis, playing a central role in the milk synthesis process. It is present in every species within the Mammalia group, while β-lactoglobulin is predominantly found in ruminant milk (Hettinga and Bijl, 2022). Other whey proteins encompass immunoglobulins, serum proteins, enzymes, hormones, and growth factors. Ewe's milk contains the highest proportion of whey protein, followed by cow's milk. β-lactoglobulin is another source of milk protein allergy; however, its lower levels in other animals, such as doe's, contribute to making their milk less allergenic than that of cows (Yasmin et al., 2020). Camel cow milk lacks β-lactoglobulin, providing it with an anti-allergenic advantage over other types of milk (Hassen, 2020).

Camel cow milk is further distinguished by the presence of immunoglobulins and antimicrobial compounds, including lysozyme, lactoferrin, and insulin equivalent to human insulin. This composition makes it a suitable choice for diabetic individuals, as they can consume it to manage their blood sugar levels (Mohammadabadi, 2020).

3.2. Milk Fats

Lipids or fats, present in the form of globules, consist of a triglyceride core surrounded by a natural biological membrane containing cholesterol, enzymes, glycoproteins, and glycolipids. This composition significantly enhances the nutritional value of milk (Lopez, 2020). The diameter of fat globules varies among different species, with buffalo having the largest diameter and doe and camel cow exhibiting the smallest (Yusuf et al., 2020), which contributes to the easier digestibility of camel cow and doe milk. Cow milk is reported to have the highest fat content, followed by ewe's milk at 6g/100g, while doe and camel cow milk have the lowest fat content (Guinee and O'Brien, 2010).

3.2.1. Cholesterol

Cholesterol is a natural component of milk, albeit at relatively low levels (less than 0.5% of milk fat), ranging between 0.01 and 0.02% depending on the animal species. Among them, doe milk exhibits the lowest levels, while buffalo milk has the highest. The milk fat globule membrane contains cholesterol, constituting approximately 95% of the sterols found in milk. In terms of cholesterol content, camel cow milk has the highest, followed by cow milk, with buffalo milk having the lowest (Gallier et al., 2020).

3.2.2. Fatty Acid Profile

Each of the five animal species has a slightly distinct composition of fatty acids, providing their milk with the ability to address various ailments. Both short-chain and long-chain fatty acids are present in the fatty acid profile; the long-chain fatty acids are further divided into mono- and polyunsaturated fatty acids (Li et al., 2023). Camel cow milk stands out by containing more polyunsaturated fats than any other type of milk, with 6–8 times fewer short-chain fatty acids (Maqsood et al., 2019). Buffalo milk, in contrast, has three times more medium-chain fatty acids such as myristic acid and palmitic acid compared to cow, ewe, and doe milk (Becskei et al., 2020). Doe milk is rich in short- and medium-chain fatty acids, including capric acid and caprylic acid, along with medium-chain triglycerides (Farag et al., 2020), which play a significant role in various therapeutic applications.

Camel cow milk, with its high content of polyunsaturated fats, may offer potential health benefits due to the presence of omega-3 and omega-6 fatty acids, associated with anti-inflammatory and cardiovascular health properties. Buffalo milk, on the other hand, is noteworthy for its higher levels of medium-chain fatty acids like myristic acid and palmitic acid, linked to therapeutic uses such as antimicrobial properties, improved digestion, and potential weight management benefits. Ewe milk contains a higher proportion of butyric acid and conjugated linoleic acid compared to cow and doe milk, making it suitable for various conditions, including malabsorption syndrome, metabolic syndrome, anemia, and bone demineralization (Dănilă et al., 2021). Cow's milk is high in fatty acids with short chains. A distinctive feature of ruminant milk is the presence of conjugated linoleic acid (CLA), known for inhibiting the development and occurrence of skin, breast, and colon cancer (Dănilă et al., 2021). Another isomer of CLA prevents obesity, reduces LDL levels, and improves the ratio of LDL to HDL in blood plasma, thereby preventing cardiovascular disease and osteoporosis (Mohan et al., 2021).

3.3. Milk Sugar

Lactose, commonly known as milk sugar, is a disaccharide primarily composed of glucose and galactose. It is present in all species with slight variations between them, being highest in cows and human milk (Table2). Despite its presence, lactose is not inherently sweet-tasting. Non-dairy milk alternatives, such as oat, coconut, rice, or soy milk, may contain fructose (fruit sugar), galactose, glucose, sucrose, or maltose. Signs of lactose intolerance, including bloating, gas, and diarrhea, are typically indicative of a lack of lactase in the body (Silberman and Jin, 2019). While the lactose content is high in ewe, cow, and buffalo milk, doe and camel cow milk are more suitable for individuals with lactose intolerance (Suri et al., 2019).

3.4. Milk Minerals

Milk is a valuable source of essential nutrients for animal bodies, including humans. It serves as a rich reservoir of calcium and phosphorus, working in conjunction with casein to facilitate milk digestion within the body (Guantario et al., 2020). Additionally, milk contains various minerals such as salt, potassium, chloride, iodine, magnesium, and iron, among other components. The presence of lactoferrin has a notable impact on the iron content of milk. Camel cow milk stands out for its abundance in iron, zinc, and copper, whereas doe milk is comparatively insufficient in these minerals (Kandhro et al., 2022). For a detailed comparison of mineral contents, refer to Table 3, which provides a comprehensive analysis (Nayak et al., 2020; Chilliard et al., 2002; Panta et al., 2021; Flis and Molik, 2021; Khan et al., 2021).

Animals	Cow	Buffalo-cow	Doe	Ewe	Camel cow
Calcium (mg)	122 ± 6	112 ±7	132 ±10	200 ±8	116 ±10
Phosphorus (mg)	119 ±5.1	99 ± 4.3	97.7 ±7.2	124 ±5.8	87.4 ±4.9
Potassium (mg)	152 ±15	92 ±7	152 ±12	136 ±13	156 ±10
Magnesium (mg)	12 ±5.3	8 ±7.3	15.8 ±9.4	18-21 ±5.8	10.5 ±2.5
Sodium (mg)	58 ±9	35 ±8	59 ±5	50 ±11	59 ±9
Zinc (µg)	530 ± 38	410 ±74	370 ±49	650 ±87	530 ±59
Iron (µg)	80 ±	161 ±48	60 ±30	110 ±60	290 ±40
Copper (µg)	60 ±20	35 ±29	80 ±45	40-68 ±30	140 ±30
Manganese (µg)	20 ±11	27 ±9	6.53 ±7	5.3-9 ±5	80 ±5
Iodine (µg)	2.1 ±3	4.4 ±3	2.2 ±4	10.4 ±3	21.07 ±7
Selenium (µg)	0.96 ±1.4	4.8 ±1.9	1.33 ±1.8	3.1 ±1.5	2.08 ±2.3

Table 3 – The amount of minerals in 100 g of milk from different animal species. These values may vary depending on the analysis tools, season, region, animal health, diet, and reproductive cycle.

3.5. Milk Vitamins

Vitamins, encompassing both water-soluble (B and C) and fat-soluble (A, D, E, and K) varieties, constitute another crucial component of milk (Table 4). Doe and ewe milk, in particular, stand out for their exceptional richness in vitamin A. The beta-carotene, a precursor or inactive form of vitamin A, present in doe and ewe milk, converts to retinol, contributing to the

milk's white coloration. Doe milk is also a noteworthy source of vitamin A, niacin, thiamine, riboflavin, and pantothenic acid. However, it contains less folic acid and vitamin B12 compared to cow's milk (Saikia et al., 2022).
Camel cow milk, on the other hand, is an outstanding source of vitamin C, containing 30 times more vitamin C than cow's milk (Table 4). It serves as a primary source of this vitamin in regions where fruit and vegetable availability is limited, such as deserts (Fufa and Haile, 2020). For a comprehensive comparison of vitamin contents from various milk sources, please refer to Table 4 (Kandhro et al., 2022; Abesinghe et al., 2020; Dhasmana et al., 2019; Rahim et al., 2020).

Animals	Cow	Buffalo-cow	Doe	Ewe	Camel cow
Vitamin A (mg)	50	69	185	146	38
Vitamin D (mg)	2.0	13	2.3	1.18	16
Vitamin C (mg)	0.94	2.3	1.29	4.16	33
Vitamin E (mg)	2.1	5.5	0.07	0.15	1.7
Thiamin (B_1) (mg)	0.045	0.052	0.068	0.08	0.048
Riboflavin (B_2) (mg)	0.16	0.135	0.21	0.376	0.168
Niacin (B_3) (mg)	0.08	0.091	0.27	0.416	0.77
Pantothenic acid (B_5) (mg)	0.32	0.192	0.31	0.408	0.368
Pyridoxine (B_6) (mg)	0.042	0.023	0.046	0.08	0.55
Folic acid (B_9) (µg)	5	6	1	5	87
Biotin (B_7) (µg)	2	13	1.5	0.93	-
Cobalamin (B_{12}) (µg)	0.357	0.36	0.065	0.712	85

Table 4 – The vitamins in 100 g of milk from different animal species. These values may vary depending on the analysis tools, season, region, animal health, diet, and reproductive cycle.

4. Health Benefits to Humans

Various authors underpin their arguments for the health benefits of different types of milk based on ingredients such as vitamins and other nutrients. However, due to the utilization of different analytical methods, materials, and study contexts, the reported concentrations of milk in the literature exhibit significant variability.

4.1. Cow’s Milk

Calcium, abundant in cow's milk, is crucial for the formation and development of bones and teeth. When calcium interacts with phosphorus, it forms calcium phosphate, essential for bone structure and strength (Kandhro et al., 2022). Cow’s milk is also rich in iodine, necessary for the thyroid hormones tri-iodothyronine and thyroxine (Table 3). It proves beneficial for infants and individuals with thyroid gland disorders. However, it may be less suitable for heart patients due to its high cholesterol content. Additionally, cow’s milk contains vitamin A, vital for the growth and development of epithelial and mucosal tissues, offering protection against toxins. It further aids in safeguarding colon cells from cancer-causing chemicals, reduces PMS symptoms during the luteal phase of the menstrual cycle, and helps prevent migraine headaches (Kandhro et al., 2022).

Calcium, with its benefits against breast cancer, plays a crucial role in blood clotting, muscle contraction, and blood pressure regulation. Cow's milk is rich in vitamin E and sulfur-containing amino acids, promoting brain development in infants and controlling infections through the antitoxin properties of vitamin A. It serves as a good source of vitamin B2 and vitamin B12, both contributing to energy production and protection against cardiovascular diseases (Walther et al., 2022). Vitamin B12 is particularly significant in the production of red blood cells and the prevention of anemia (Madasheva and Abdiev, 2023).

4.2. Buffalo's Milk

Buffalo milk boasts a higher protein content compared to cow's milk, playing a vital role in muscle growth, repair, and the production of enzymes, hormones, and antibodies. Abundant in vitamins and minerals, buffalo milk contributes to maintaining healthy bones, teeth, and overall body function (Table 3). The natural prebiotics present in buffalo milk support a healthy gut microbiome, enhancing digestion and nutrient absorption (Vargas-Ramella et al., 2021). Its low cholesterol and high unsaturated fat content contribute to improved heart health and cholesterol level management (Abesinghe et al., 2020). The proteins and bioactive compounds in buffalo milk have immune-boosting properties against infections and diseases. Moreover, adults consuming buffalo milk face a lower risk of developing a milk allergy. The low cholesterol content of buffalo milk, as indicated in Table 2, makes its products beneficial for both cardiovascular patients and health-conscious individuals. When compared to cow's milk, buffalo's milk not only contains more calcium but also boasts a superior calcium-phosphorus ratio (1:80) and lower levels of sodium and potassium, making it a preferable nutritional supplement for young children (Kandhro et al., 2022). Additionally, buffalo milk stands out as a rich source of vitamin D, as detailed in Table 4.

4.3. Doe's Milk

Milk from a doe contains essential nutrients such as protein, calcium, phosphorus, potassium, and vitamins A and D, contributing to bone health, immune function, and overall well-being (Dhasmana et al., 2021). Its calcium and phosphorus exhibit high bioavailability, ensuring easy absorption and utilization by the body.(Table 3) The presence of fatty acids and minerals in doe's milk contributes to enhanced skin health. For those allergic to cow's milk, doe's milk serves as a viable substitute. The protein structure in doe's milk differs from that in cow's milk, potentially reducing the risk of triggering allergic reactions in some individuals. In certain regions, doe milk is occasionally used as a substitute for cow's milk. It closely resembles a woman's milk, making it a healthy option for those following a diet (Nayik et al., 2021). Doe's milk is rich in medium-chain fatty acids, which are beneficial for treating malabsorption syndrome and steatorrhoea. These fatty acids are designed to lower cholesterol levels and dissolve cholesterol deposits in the arteries (Bharti, 2022). Rich in zinc and selenium, two essential micronutrients for preventing neurological illnesses and defending against antioxidants, doe milk also contains high levels of calcium and phosphorus (Table 3), which support healthy bones and promote the growth of newborns (Bhatia and Tandon, 2021).

4.4. Ewe's Milk

Ewe milk, akin to doe milk, stands out for its inherent richness in nutrients, flavor, and health benefits compared to cow milk (Table 1). It boasts higher levels of protein, calcium, and vitamins A, B, D, and E, along with essential minerals such as zinc, magnesium, and phosphorus (Devi et al., 2019). Ewe milk is particularly abundant in crucial branched-chain amino acids (BCAAs) like leucine, valine, and isoleucine, promoting protein synthesis. Despite having a higher fat content than cow's or doe's milk, the predominant unsaturated fats in ewe milk do not adversely impact cholesterol levels, and it is generally easier for infants to digest (Devi et al., 2019).

4.5. Camel Cow's Milk

Camel cow's milk, distinguished by its opaque white color, faint sweetish odor, and occasional salty taste, is renowned for its resemblance to human milk and its rich content of essential vitamins, proteins, and minerals. (Table 3).The presence of antioxidants in camel cow milk offers cellular protection against oxidative damage, carrying implications for reducing the risk of diseases such as cancer, diabetes, and cardiovascular disorders. Particularly significant in arid regions, spanning from Northern Africa and the Middle East to the Balochistan province of Pakistan, camel cow milk serves as a valuable source of nourishment for nomadic populations (Marghazani, 2023). In these challenging environmental conditions, the consumption of camel cow milk provides essential nutrition, supporting the well-being of individuals in desert settings. Noteworthy for its suitability for lactose-intolerant or allergic individuals due to its diverse protein profile and anti-diarrheal qualities (Rahim et al., 2020), camel cow milk encompasses various fat-soluble and water-soluble vitamins, including A, E, D, and B, with a particular emphasis on vitamin C. (Table 4) Additionally, it serves as a rich source of minerals, notably calcium and potassium. In certain regions of the world, camel cow milk has been traditionally utilized as a therapeutic approach for individuals with autism, with studies indicating improvements in symptoms and ongoing research exploring the potential impact of replacing cow milk with camel cow milk for children and adults with autism (Al-Ayadhi et al., 2022).

5. Commercial Products

5.1. Commercial Products of Cow's Milk

The most widely consumed form of milk globally is cow's milk, which represents over 85% of all milk produced by commercial dairy products in most countries (Pulina et al., 2018). India and Pakistan are the leading producers of cow milk worldwide, followed by China, Egypt, and Nepal, making up the top five (Hegde, 2019). Cow milk is utilized to produce various products such as cheese, butter, yogurt, fresh cream, ice cream, and condensed and evaporated milk, each contributing its distinctive taste, texture, and nutritional advantages. Whey protein, extracted as a byproduct of cheese production, is further processed into whey protein powder, gaining popularity among athletes and fitness enthusiasts (Elshazly and Youngs, 2019).
Given its staple status in many countries, cow milk maintains high demand globally, ensuring a stable market for milk producers and processors. To maximize profitability, cow milk is processed into higher-margin value-added products. Countries with surplus

milk production have the opportunity to access international markets, fostering foreign exchange and contributing to economic growth, as the derived products exhibit significant export potential (Gebreyohanes et al., 2021).

5.2. Buffalo Cow vs. Cow's Milk

Buffalo milk holds a significant commercial presence, ranking second overall in regions where buffaloes are bred for milk production (Pantoja et al., 2022). This milk is utilized in the production of various popular products, including cheese, yogurt, kefir, ice cream, and butter. Notably, buffalo milk proteins, particularly whey proteins, exhibit greater heat resistance compared to cow's milk. The unique tactile quality of buffalo milk makes it a preferred choice for manufacturing mozzarella cheese, with the term "mozzarella" legally restricted to meals made exclusively with buffalo milk as per Italian legislation (Cervelli et al., 2021).

Buffalo milk contains higher levels of immunoglobulins, including lactoferrin, lysozyme, and lactoperoxidase, making it suitable for the production of a range of special dietary and health products (Numpaque et al., 2019). Additionally, the appropriate sulfur level in cow's milk acts as a brain tonic, promoting cognitive alertness and physical activity. Cow's milk is rich in vitamin E, (Table 4), benefiting the reproductive system and enhancing sexual health (Lata and Mondal, 2021). With less water and higher fat content, buffalo milk has a thicker consistency, making it ideal for the production of high-fat dairy products such as butter, ghee, cheese, and ice cream (Erdal et al., 2022).

5.3. Doe Milk in Skin Care Products

Doe milk has a rich history of use in skincare and cosmetic treatments, dating back to ancient times, highlighting its enduring popularity for these purposes (Sánchez et al., 2022). The milk is particularly valued for its skincare and aesthetic properties, with handmade organic soaps being a notable product. These soaps are especially beneficial for dry or sensitive skin due to the presence of glycerin, a moisturizing and hydrating agent. Glycerin is extracted and commercially sold, contributing to economic activities (Ganesh et al., 2022).

Furthermore, doe milk soap contains lactic acid, an alpha-hydroxy acid commonly found in cosmetic products. Alpha-hydroxy acids play a role in eliminating dead skin cells and refining the skin's surface, enhancing its texture (Sumarmono, 2022). In regions where animals are raised for personal or commercial purposes, ewe and doe milk are commonly available and consumed, particularly for their potential benefits in skincare and cosmetic applications.

5.4. Ewe's Milk in Beauty and Dairy Products

Ewe's milk holds significant value in the beauty industry due to its beneficial skincare properties. Rich in natural fats and proteins, ewe's milk is prized for its ability to nourish and moisturize the skin. It is a common ingredient in the production of soaps, creams, lotions, and various cosmetic products, contributing to enhanced hydration and softening of dry or sensitive skin (Mohapatra, 2021). The composition of ewe's milk, including vitamins, minerals, and antioxidants, further supports its potential to promote healthy skin. (Tables 3 and 4) Ewe's milk soaps are recognized for their effectiveness as skin moisturizers, boasting nearly twice the amount of vitamins and minerals compared to other milk soaps and being enriched with skin-nourishing butter, fats, and proteins (Ospanov and Toxanbayeva, 2020).

In addition to its role in the beauty industry, ewe's milk holds high esteem in the dairy product sector. Notable for its unique flavor and nutritional composition, ewe's milk contains higher levels of solids, including proteins, fats, and minerals, compared to cow's milk (Table 1). This makes it an excellent choice for the production of diverse dairy products, including cheese, yogurt, butter, and ice cream. Ewe's milk cheeses, in particular, are renowned for their rich, creamy texture and distinctive flavor profiles. In the realm of ice cream, ewe's milk contributes to a smooth and creamy texture with a lower fat content (less than 7%), providing a delightful and crisp flavor to the ice cream, unlike its cow's milk counterpart with 12% fat (Punia et al., 2020). The utilization of ewe's milk in both beauty and dairy products not only offers unique alternatives but also contributes to the economic viability of ewe farming, supporting agricultural communities, and fostering rural development.

5.5. Camel Cow Milk and its Commercial Products

Camel cow milk, despite being produced in smaller quantities compared to cow's milk, is gaining recognition for its substantial skincare benefits. Enriched with natural alpha-hydroxy acids known for their skin-enhancing properties, camel cow milk is incorporated into soaps and lotions designed to capitalize on these advantages, offering moisturizing and nourishing effects for skincare applications (Bhatesh et al., 2021). The unique qualities of camel cow milk extend beyond skincare, as it finds application in diverse culinary delights and food products. From gourmet chocolates with a distinctive flavor profile and potential health benefits to creamy-textured ice cream and artisanal cheeses providing a unique alternative to traditional dairy-based options, camel cow milk has found its place in the culinary landscape (Verma and Rout, 2022).

Moreover, the dehydration and processing of camel cow milk into powdered form contribute to its convenience and extended shelf life, making it a versatile ingredient for various food and beverage applications (Muthukumaran et al., 2022). The commercialization of camel cow milk products has played a pivotal role in increasing their availability and accessibility to consumers. However, it's important to note that due to the limited availability of camel cows, commercial purchase options are typically restricted to locations where these animals are found (Seifu, 2023). Despite the challenges posed by limited availability, camel cow milk's unique qualities and benefits are becoming more widely enjoyed through the innovative development of commercial products.

6. Milk Allergies and Intolerance

Cow's milk is a common source of milk allergies, with proteins in cow's milk capable of triggering allergic reactions and lactose intolerance in susceptible individuals. Although rare in adults, these immune system responses are among the most prevalent food allergies in children. Cow's milk allergy (CMA) is estimated to affect approximately 5% of infants and young children, presenting a significant concern during this developmental stage (Tosca et al., 2023). It's crucial to recognize that milk from other mammals can also induce allergic reactions, emphasizing the need for alternative milk options, particularly for individuals with known allergies or sensitivities to specific animal milk, such as cow's milk.

For those with allergies or sensitivities, plant-based milk alternatives provide a viable option as they do not contain the allergenic proteins found in animal milk. Access to alternative milk choices ensures that individuals can meet their nutritional needs without compromising their health or experiencing adverse reactions associated with milk allergies.

6.1. Cow Milk Allergies and Symptoms

Cow milk yogurt can pose challenges for individuals with cow milk allergies, leading to typical allergy symptoms such as itching, lip enlargement, skin rashes, and dizziness. This allergic response is often associated with the presence of lactose in cow's milk, as approximately 4.7% of cow's milk is composed of lactose. Many individuals experience difficulties digesting lactose due to lactase deficiency (Nayak et al., 2020). In addition to concerns related to milk allergies, there are broader considerations in the dairy industry. Recombinant bovine growth hormone (rBGH) is utilized to enhance milk production in cows. However, studies suggest that this practice may lead to significant health issues in cows, including mastitis, infertility, and lameness (Mitz and Viloria, 2019). Cows treated with rBGH may also face an elevated risk of udder infection (mastitis), necessitating increased antibiotic use and potentially impacting the cows' immune systems (Shiva, 2019).

While hormones like rBGH are present in minimal amounts in milk and are considered safe for human consumption, milk from rBGH-treated cows has been found to have higher levels of the growth factor IGF-1. Elevated levels of IGF-1 have been associated with negative effects on human health, including an increased risk of cancer (Raux et al., 2022). These considerations highlight the importance of understanding the broader implications of milk production practices and their potential impact on both animal welfare and human health.

6.2. Buffalo Cow Milk Allergies and Reactions

Buffalo milk allergies are relatively uncommon compared to cow milk allergies, but they can still occur. Allergic reactions to buffalo milk may manifest as skin rashes, hives, itching, swelling, and, less frequently, gastrointestinal symptoms such as vomiting, diarrhea, and abdominal pain (Chilliard et al., 2002). While buffalo milk does contain lactose and may pose challenges for individuals with severe lactose intolerance, it generally contains lower levels of lactose compared to cow's milk, making it a potentially suitable alternative for some individuals.

Interestingly, buffalo milk might offer benefits for individuals with eczema and psoriasis due to its potential anti-inflammatory properties and the presence of bioactive compounds that could promote skin health (Lambrini et al., 2021). The mechanisms through which buffalo milk may enhance metabolism, prevent anemia, and strengthen the immune system are not precisely defined. However, the nutrient composition of the milk, including proteins, vitamins, minerals, and bioactive compounds, could contribute to these potential health benefits. It's important to note that individual responses to these health claims may vary.

6.3. Doe Milk Allergies vs. Benefits

Doe milk contains lactose, and individuals with severe lactose intolerance should avoid it. However, those with mild lactose intolerance may be able to consume moderate amounts of doe's milk and its byproducts, such as yogurt and cheese, as they contain less lactose. Fermented doe's milk products are often considered a good alternative for individuals allergic to cow's milk. Doe milk is known to be easier to digest due to its smaller fat globules and a higher proportion of medium-chain fatty acids. This makes it better tolerated by individuals with sensitive digestive systems or lactose intolerance. The main advantages of doe's milk include causing fewer allergic reactions than cow's milk and being easier to digest and absorb (Panta et al., 2021). Drinking doe milk containing casein micelles may help prevent gastrointestinal problems, vomiting, diarrhea, constipation, and respiratory problems in infants (Mohammed and Jimma, 2018).

Regular consumption of doe's milk is associated with numerous health benefits for humans, including weight gain, bone mineralization, maintenance of hemoglobin levels, support for the immune system, prevention of cancer and heart disease, anti-aging effects, improvement in skin and hair health, kidney health, relief from arthritis, asthma, heavy metal poisoning, and hypertension (Savita and Divya, 2021). However, individual responses to these health benefits may vary.

6.4. Ewe Milk Proteins As Allergens

Drinking ewe milk may occasionally cause allergies and complications, particularly in individuals allergic to the protein casein found in ewe milk. Symptoms of ewe milk protein allergy (MPA) may include digestive problems, skin rashes, respiratory issues, and, in severe cases, anaphylaxis. Ewe's milk, like doe milk, contains conjugated linoleic acid (CLA), known for its anti-cancer properties, with ewe's milk having the highest proportions of CLA. Additionally, the medium-chain fatty acids in ewe's milk contribute to the prevention of various cardiac disorders, including epilepsy in children, gallstone formation, and cystic fibrosis (Flis and Molik, 2021). The controlled concentration of medium-chain fatty acids in ewe's milk is associated with a reduction in cholesterol accumulation in the body.

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For individuals with eczema and asthma, the National Eczema Society and the Asthma Research Council recommend drinking ewe's milk to potentially relieve symptoms. Ewe's milk may also be beneficial for those who experience nighttime bedwetting problems (Mazandarani et al., 2022). As with any health recommendation, individual responses may vary, and it's advisable to consult with a healthcare professional for personalized advice.

6.5. Benefits of Camel Cow Milk Outweigh the Risks

Camel cow milk is generally considered safe to drink, and regular consumption is associated with several health benefits. It has been reported to lower the risk of cardiovascular disease and help regulate blood sugar levels. Lactoferrin, a component present in camel cow milk, possesses antiviral, antibacterial, and anticancer properties. The milk is also rich in insulin, which is crucial for the treatment of diabetes types 1 and 2. Camel cow milk has immune-boosting properties and lacks typical allergens found in cow's milk, such as beta-casein (Khan et al., 2021).

Comparing the fat composition of camel cow milk to that of cow, buffalo, and ewe milk, it has a lower concentration of short-chain fatty acids, linoleic acids, and polyunsaturated fatty acids, which are considered favorable for brain function. In comparison to cow milk, camel cow milk contains significantly higher levels of iron, vitamin C, and antiviral and antibacterial characteristics. The milk is reported to be beneficial for individuals with conditions such as anemia, cancer, lactose intolerance, hepatitis, or heart problems. Camel cow milk also contains antibodies against cancer, Alzheimer's disease, and hepatitis B (Konuspayeva, 2020).

The high vitamin C content of camel cow milk is suggested to provide protection against diseases linked to vitamin C deficiency (Table 4). Additionally, the insulin present in camel cow milk is produced in a way similar to the human body's production, making it suitable for diabetic patients. Lactoferrin, another important component, has anti-viral and anti-tumor properties. The absence of β-lactoglobulin in camel cow milk gives it an anti-allergenic property, making it easily consumable by individuals with milk allergies (Hassen, 2020).

7. Food Security

To avoid foodborne illnesses and advance public health, it is essential to ensure the safety of milk. Fresh or raw milk that is obtained straight from local sources and has not been pasteurized may be more nutritious, but it also raises safety concerns because it may contain harmful bacteria from improper handling and unhygienic conditions. This poses risks to public health, especially in regions with limited resources and infrastructure for ensuring proper milk safety (Akinyemi et al., 2021). In contrast, milk that is packaged goes through pasteurization, which involves heating the milk to a particular temperature in order to eradicate harmful bacteria, improve its safety, and lengthen its shelf life. Packaged milk is widely available in various retail outlets, making it more accessible to consumers (Khayrullin and Rebezov, 2023).

The controversy between pasteurized and unpasteurized milk is ongoing. While unpasteurized milk is considered by some to have more natural qualities, it carries a higher risk of bacterial contamination, including pathogens such as Salmonella and E. coli, which can cause foodborne illnesses. Individuals with compromised immune systems or inflammatory bowel disease (IBD) are advised against consuming raw milk (Paswan and Park, 2020).

Differentiating between food safety and food security is crucial. Food safety focuses on ensuring that the food consumed is free from contaminants and poses minimal health risks. Pasteurization significantly contributes to enhancing the safety of milk by reducing bacterial pathogens. On the other hand, food security considers broader aspects such as access, availability, and utilization of food to address hunger, malnutrition, and related issues. It encompasses economic, social, and environmental factors affecting individuals' ability to obtain and consume safe and nutritious food (Clapp et al., 2022). Enhancing the safety of milk products is not only essential for public health but can also contribute to poverty reduction by ensuring the health and well-being of individuals and communities. Investing in food safety measures creates employment opportunities, particularly for women, in areas such as food processing, quality control, and hygiene practices, promoting gender equality and empowerment (Afzal and Faisal, 2018).

8. Milk Alternatives and Animal-Free Dairy

Dietary preferences are dynamic and vary across regions. In Asia, a significant portion of the population, 19%, follows a vegan diet, and 65% of Asian citizens face lactose intolerance after infancy. Similarly, in Europe, 13.9% prefer drinks with vegan claims. Globally, lactose malabsorption affects a substantial portion, with estimates ranging from 66-78%, and the prevalence is highest in Africa and Asia (Chien et al., 2010).

Obesity is another factor influencing dietary choices. In the United States, where 32% of the population is classified as obese, there is a growing interest in fat and carb-free diets. In many countries with a strong dairy industry, individuals can access fresh, unprocessed milk locally. However, improper handling and unsanitary conditions make fresh milk in these regions potentially dangerous due to an unknown bacterial profile (Girma et al., 2014). For places where fresh dairy products or refrigeration are unavailable, milk powder (MP) serves as an alternative. By extracting water from milk, MP can be preserved for months or even years. While it contains the same vitamins and minerals as regular milk and is easy to blend into drinks and smoothies, it may have a distinct flavor. Additionally, MP may contain oxidized cholesterol, an artificial substance added to prolong shelf life that has been associated with cardiovascular disease risk (Kavas et al., 2004; Risso et al., 2022).

Manufacturers of dairy alternatives use various methods to replicate the qualities of conventional milk. One such method is the extraction of plant proteins through pressing, and another involves fermentation processes. A particular kind of fermentation called "precision fermentation" uses microorganisms that are fed a carbon source in bioreactors to create proteins that resemble milk. These proteins are then separated, filtered, and combined with other substances to impart a dairy-like taste, texture, and functionality to alternative milk products. Precision fermentation may involve transferring a cow whey protein sequence to the microflora, producing the desired protein via fermentation. This complex manufacturing process combines biological techniques and specialized equipment to create dairy alternative products closely resembling conventional milk in sensory attributes and functionality (Tangyu et al., 2019).

8.1. Animal Cruelty in Dairy Industry and Related Health Risks

The global dairy industry has witnessed increased milk production due to technological advancements, but this growth has raised concerns about animal welfare. Issues such as animal abuse, inhumane practices, unsanitary conditions, and the use of unnecessary chemicals, drugs, and antibiotics have prompted ethical concerns. Animals kept indoors often experience limited movement and restricted natural behaviors, and practices like separating mother cows from their calves and disposing of male calves raise ethical questions (Kumar et al., 2022).

Efforts to address these concerns involve improving housing conditions, promoting bonding between mother cows and calves, finding alternative purposes for male calves, preventing health issues, supporting sustainable breeding practices, providing outdoor access, and encouraging adherence to animal welfare standards through certification programs (Stygar et al., 2021). Collaboration among dairy farmers, researchers, and animal welfare experts is crucial for sharing knowledge about best practices (Wynands et al., 2021). Apart from animal welfare, concerns exist about potentially harmful substances in dairy milk. Practices involving antibiotics or growth hormones to boost milk yield are considered unethical, and strict regulations in many countries monitor and control their use in dairy farming. Environmental contaminants, such as pesticides and heavy metals, can enter milk through the cow's diet or the environment, posing health risks (González-Montaña et al., 2019).

Addressing these issues requires implementing more compassionate dairy practices. However, economic factors, as the dairy industry is profit-driven, often prioritize cost-effective, inhumane practices over ethical alternatives. Resistance to change, deep-rooted traditions, a lack of regulation, and consumer demand for lower prices further complicate the adoption of more humane practices (Verrinder et al., 2019; Dankar et al., 2022; de Boer et al., 2022). In some cases, powerful industry lobbies may influence policies, making it challenging to enforce stricter animal welfare standards (Hernandez et al., 2022). Awareness and education about ethical issues, along with a shift in consumer preferences, can play a role in encouraging the adoption of more humane practices over time.

8.2. Milk Alternatives

Indeed, there is a growing variety of non-dairy milk alternatives catering to diverse dietary preferences and needs. Plant-based options such as almond, soy, rice, hemp, cashew, and coconut milk have become increasingly popular due to factors like lactose intolerance, milk protein allergies, vegan lifestyles, and personal taste preferences (Jayarathna et al., 2021; Ramsing et al., 2023; Thakur et al., 2022).

These milk alternatives offer a range of nutritional profiles, flavors, and textures, providing individuals with choices that align with their specific dietary requirements. Fortified versions of these alternatives can also provide essential nutrients like calcium and vitamin D, making them nutritionally comparable to traditional cow's milk. The availability of these alternatives has expanded the options for consumers, allowing for greater flexibility in choosing products that suit individual preferences and values (Park, 2021). Whether for ethical reasons, health considerations, or taste preferences, non-dairy milk alternatives have become a staple in many households, contributing to the diversity and inclusivity of the modern food landscape.

8.2.1. Soy Milk

Soy milk has indeed gained widespread acceptance as a valuable dietary component, and advancements in production techniques have resulted in a variety of soy milk products, including sweetened, unsweetened, flavored, total, and low-fat options (Rincon et al., 2020). Soy milk is considered a nutritionally rich alternative to cow's milk, as it contains similar amounts of protein, calcium, vitamins A and D, and riboflavin.

One notable component of soy milk is isoflavones, which are natural antioxidants associated with a reduced risk of heart disease. Research suggests that a daily intake of 10mg of isoflavones may contribute to a 25% reduction in breast cancer recurrence (Park et al., 2021). Additionally, soy milk has been found to be beneficial for women during and after pregnancy and menopause, as it may help reduce hot flashes (Kim, 2021). While soy milk can be a nutritious addition to the diet for many individuals, it's important to note that it is not a suitable substitute for breast milk or infant formula for human infants.

8.2.2. Almond Milk

Almond milk is a popular culinary ingredient that can be used for ice cream and other confections because of its creamy texture. It is made from ground almonds and water, and it is frequently fortified with vitamins and minerals (Xypolitaki, 2023). However, it's important to note that almond milk has a lower protein content compared to dairy or soy milk, with a cup of sweetened almond milk containing only 1.02g of protein.

Fortified almond milk is a good source of vitamin E and is generally lower in calories than cow's milk, especially if it has minimal added sugar. However, almond milk may not naturally provide the same levels of vitamins, minerals, and fatty acids as dairy milk unless it is fortified. Despite its lower nutritional profile, almond milk can be a suitable substitute in baking and other recipes, offering a dairy-free option for those with dietary preferences or restrictions (Park, 2021). It's essential for individuals to choose almond milk products that are fortified if they are seeking a more nutritionally complete alternative to traditional dairy milk.

8.2.3. Rice Milk

Rice milk can be a suitable option for individuals with food allergies or intolerances, as it is often free of common allergens such as soy, gluten, and nuts. Rice milk has a thin and liquid consistency, which may affect its suitability for certain cooking or baking applications. The composition of rice milk typically includes boiled rice, brown rice syrup, and brown rice starch. While it may be high in carbohydrates, it tends to be low in protein. The nutritional content can vary based on the manufacturing process and whether sweeteners are added. On average, one cup of plain rice milk contains approximately 115 calories, 2.37 grams of fat, 22.4 grams of carbohydrates, 0.68 grams of protein, and 288 milligrams of calcium, along with trace amounts of various vitamins and minerals (Plengsaengsri et al., 2019). Despite its limitations in cooking or baking, rice milk can be a suitable dairy alternative for those who need to avoid specific allergens or prefer a lighter beverage option.

8.2.4. Coconut Milk

Coconut milk is produced by scraping and squeezing the flesh of mature coconuts through a strainer, and stabilizers may be added during the manufacturing process. It is a soy and gluten-free milk that offers a texture similar to whole milk and has a distinct nutty flavor. This makes it a versatile option, particularly in baked goods, and it serves as a good alternative for individuals with multiple food allergies.

The nutritional profile of raw coconut milk is unique compared to animal milk. Approximately 100 grams of raw coconut milk contain around 230 kcal, 23.8 grams of total fat, 67.6 grams of moisture, 3.3 grams of sugars, 2.9 grams of protein, 2.3 grams of sucrose, 0.7 grams of ash, 5.5 grams of carbohydrates, and 16.0 milligrams of calcium, along with trace amounts of various vitamins and dietary fiber (Tulashie et al., 2022).

One notable component of coconut milk is lauric acid, an antioxidant known for its potential to prevent stroke and heart disease. Lauric acid helps remove free radicals and protects lipids, proteins, and DNA from the effects of oxidative stress. Additionally, coconut milk contains medium-chain triglycerides (MCTs), which are known to stimulate energy processes, contributing to thermogenesis and potentially promoting weight loss (Bharti et al., 2021).

8.2.5. Other Plant-based and Non-Bovine Milk in the Future

The landscape of non-dairy milk alternatives is continually expanding, offering a wide variety of plant-based options. As mentioned in various studies (Kehinde et al., 2020; Yu et al., 2023; Srujana et al., 2019; Sethi et al., 2016; Zeldman et al., 2020; Tangyu et al., 2022; Ding et al., 2020), consumers have access to a diverse range of substitutes made without animal-based ingredients. These alternatives cater to various dietary preferences, including those based on plant sources such as soy, almond, rice, hemp, cashew, and coconut.

In addition to traditional plant-based milks, an emerging and innovative category is cell-based milk, sometimes referred to as "lab-grown milk" or "cultured milk." This type of milk is distinct from traditional plant-based alternatives as it is produced using cellular agriculture techniques. The process involves culturing animal cells in a laboratory setting, similar to how lab-grown meat is created (George et al., 2023).

Cell-based milk represents a forward-looking approach to milk production, aiming to replicate the taste and nutritional composition of conventional cow's milk while addressing environmental and ethical concerns associated with traditional dairy farming. Although still in its early stages, the development of cell-based milk has the potential to revolutionize the milk industry by providing a sustainable and cruelty-free alternative to traditional dairy products (George et al., 2023). As this technology advances, it may become an increasingly viable option for consumers seeking more sustainable and ethical choices in their milk consumption. A few commercially available plant-based milk product varieties along with their health benefits are shown in Table 5.

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Plant-Based Milk Type	Organization and location	Ingredients	Notable Features	Health Benefits
Quinoa Milk	Good Groceries Red Hook-New York, USA	Filtered water, quinoa	Creative plant-based substitute	Quinoa's high nutritional content, therapeutic benefits, and gluten-free status may be advantageous to a variety of high-risk consumer groups, such as kids, the elderly, athletes, those with lactose intolerance, and people with different medical conditions.
Cashew Milk	Silk, Colorado, U.S.	Cashews, cane sugar, almond butter, vitamins, minerals	Decadent properties with added nutrients	Alternative for lactose intolerant or allergic to the proteins in cow's milk. It has fewer calories than cow's milk, making it an option to lose weight while still supplying comparable amounts of calcium, vitamin A, and vitamin D.
Sunflower Milk	Sunrich Naturals; USA	Sunflower kernels	Unique sunflower-based milk	Nut-free composition, making it a good option for people with celiac disease and nut allergies.
Oat Milk	Earth's Own Food Company; Vancouver, Canada	Oats, calcium, vitamin D	Mild, sweet flavor, creamy consistency	Increased thickness can lengthen the time for it to pass through the digestive tract, which is linked to lower blood glucose levels and a decrease in both total and LDL cholesterol, producing a hypocholesterolemic effect.
Walnut Milk	Elmhurst Nutmilk; Elma-New York, USA	Filtered water, walnuts, cane sugar, salt, natural flavors	Walnut-based milk from Elma, New York, USA	Consuming walnut milk regularly is linked to lower cholesterol, protection against diabetes, the delivery of antioxidant characteristics, and possibly prebiotic effects.

Table 5 – Some commercially available varieties of plant-based milk products and their health benefits

9. Conclusion

In conclusion, the diverse array of milk types, encompassing cow's, buffalo's, doe's, camel cow's, and ewe's milk, imparts a spectrum of nutritional and health advantages. Each variant of milk possesses distinctive components contributing to holistic health, potentially mitigating diverse diseases. The fatty acid profiles and the inclusion of conjugated linoleic acid in ruminant milk underscore its potential for averting conditions such as cancer, obesity, and osteoporosis without adverse effects on cholesterol levels (Badawy et al., 2023). While animal milk enhances the immune system, challenges arise from allergenic proteins and lactose intolerance for certain individuals. Doe or camel cow milk, offering a lower lactose content, facilitates easier digestion for lactose-intolerant individuals. Although doe milk may induce allergic reactions in specific cases, it exhibits potential for treating particular allergic conditions. Ewe milk demonstrates promise for individuals dealing with asthma and eczema, particularly in applications related to beauty and cosmetic products (Mohapatra et al., 2019).

The discernment of the merits and demerits of each milk type is imperative for making judicious choices in consonance with individual dietary prerequisites and health objectives. The diverse health benefits inherent in these milk varieties empower individuals to tailor their milk consumption to address specific nutritional requirements or health concerns. Strategic incorporation of various milk types into one's dietary regimen at appropriate intervals fosters a holistic approach to health optimization. Notably, processed dairy milk undergoes periodic testing for hormones, antibodies, and contaminants on dairy farms. Numerous dairy alternatives often exhibit equivalent or superior nutritional value compared to dairy milk, encompassing heightened levels of calcium, vitamin D, and vitamin A, coupled with diminished health risks relative to raw dairy milk (Singhal et al., 2017). Transitioning from conventional dairy milk does not necessitate forsaking nutritional benefits, as animal-free alternatives to organic dairy products abound, providing a viable option for those seeking alternatives. The decision between conventional milk and its substitutes can yield comparable positive outcomes in terms of nutritional content. It is imperative to underscore that despite the myriad health benefits associated with milk and its alternatives, individual sensitivities and allergies merit careful

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consideration. Armed with this knowledge, individuals can make informed decisions about milk consumption, leveraging its potential benefits for holistic health and well-being.

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The data used in this study are available from the corresponding author, A.M.

Conflicts of interest

The authors declare no conflict of interest.

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