PLANT-BASED MILK ALTERNATIVES: RISING TREND AND NUTRITIONAL PERSPECTIVE

Abstract

With the growing emphasis on health, ethical values, and sustainability, consumers have shifted towards reducing their consumption of animal-based food products and showing a tendency for plant-based alternatives. The recent coronavirus pandemic has further heightened consumer interest in novel and diverse products. Consequently, the food industry has responded by developing innovative plant-based beverages that closely imitate physicochemical and sensory properties of animal sources milk.

The origins of plant-based milk alternatives, which continue to enjoy popularity today, can be traced back to ancient Greece. Plant-based milk alternatives are particularly prevalent in regions where lactose intolerance is more common, such as parts of Asia, Africa, and South America, gradually replacing animal-derived milk. The rising popularity of plant-based milk alternatives can be attributed to several factors, including lactose intolerance, milk allergies in infants, veganism, concerns about animal welfare, the use of antibiotics and hormones in dairy animals, and the environmental impact of animal agriculture.

Plants are widely recognized for their nutraceutical and functional food properties, owing to their rich mineral and vitamin content, antioxidants, dietary fibers, and other health-promoting components. Although fortification can partially address mineral and vitamin deficiencies in plant-based milk alternatives, it is significant that these alternatives fall short in terms of other

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essential nutrients, such as protein. Animal milk offers a superior protein and calcium profile compared to plant-based milk. While soy milk is considered a protein equivalent to animal milk, it only provides one-fifth of the calcium content. Moreover, even if the protein quantity is the same, the composition of amino acids in the protein affects the body's utilization rate. Additionally, plant-based milk alternatives lack other crucial nutrients like vitamin D, vitamin B12, vitamin B2, vitamin E, iodine, and folic acid than animal milk.

On the other hand, animal proteins exhibit higher digestibility and bioavailability compared to plant proteins. Thus, plant-based milk alternatives generally have lower protein, mineral, and vitamin content than animal milk, despite providing the same amount of protein. Furthermore, the bioavailability of these nutrients in plant-based alternatives is lower than that in animal milk.

Advocates of plant-based milk alternatives argue that these products offer several advantages over animal milk, such as reduced environmental impact, lower contribution to global warming, lower water usage in production, and higher overall nutritional value. However, the deficiencies in protein content and variable nutritional composition of plant-based milk, coupled with higher prices and concerns regarding the use of fillers and added sugars, contribute to consumer confusion and affect their preference for plant-based products.

From a commercial standpoint, several factors contribute to the market growth of plant-based milk alternatives. These include the trend of consumers seeking natural products, increased interest in herbal and traditional products, lactose intolerance, the popularity of plant-based alternatives among the younger Generation

Z, acceptance of natural products by Generation Y, and easy access to these products through e-commerce and other sales channels.

Keywords: plant-based milk; nutrition; animal milk; healty diet; health benefits; market share

I. INTRODUCTION

Recently, the food industry has emphasized the development of innovative food to meet the demands of consumers' new product expectations by creating alternative foods that are healthier and more functional. Beverages are no longer solely considered thirst-quenching drinks but are now being developed with functional features in mind. These beverages aim to provide positive health effects such as increased energy, anti-aging properties, fatigue and stress reduction, and targeting specific diseases. This shift in consumer demands has led to significant developments in the beverage industry and the increase in urbanization through technological advancements has accelerated product innovations. One crucial functional aspect that has emerged in response to various challenges, such as cow-related allergies, lactose intolerance, calorie concerns, and hypercholesterolemia, is the introduction of alternative beverage options [1].

The rising trend for plant-based protein sources has significantly contributed to the growing popularity of plant-based milk alternatives. As more individuals adopt vegetarian, vegan, or flexitarian diets, they seek alternative protein sources, including plant-based options. Plant-based milk (coconut, oat, soy, and almond etc.) offers a viable substitute for animal-based milk products. Over the past decade, the consumption of these products has witnessed a noticeable increase. While many of these products are brought to market using the term "milk," the U.S. Food and Drug Administration (FDA) defines milk as “the lacteal secretion obtained from healthy cows through complete milking, practically free from colostrum” [2]. Another definition of milk in The Britannica Encyclopedia is “the liquid secreted by the mammary glands of female mammals to nourish their young, containing all the necessary nutrients in sufficient quantities”. Otherwise, plant-based milk alternatives are beverages produced from plants and imitate the appearance of animal milk. These milk alternatives are characterized as aromatic drinks of non-animal origin, manufactured using plant extracts and flavored with water. Plant-based milk alternatives are created by extracting liquids from various plant sources such as tree nuts, legumes, seeds, or grains. It is worth noting that while the FDA has established standards of identity or compositional requirements for milk, it has not set similar standards for milk alternatives. As a result, plant-based drink products cannot be labeled as milk and have adopted the term "plant-based milk alternatives" [3] The European Court of Justice has also ruled against using dairy names (such as milk, yogurt, cheese, etc.) for plant- based products (EU regulation 1308/2013). The composition of plant-based milk alternative products, including their nutrient profiles, may vary depending on such factors; as the specific plant sources used, processing methods employed, and any additional ingredients added during production. It is advisable to review the nutritional information provided on product labels to understand the specific nutrient content of each plant-based milk alternative [4].

Although there are concerns and regulations about terminology on plant-based milk alternatives, these products are known well in Europe for the following reasons. First, Europe was full of ancient forests in the past centuries for gathering wild nuts, and the dry grains could be stored for a long time for making milk. Second, crushing and filtering grains through cloth was common knowledge as an emulsifying technique throughout eras and civilizations. The other one is that animal milk cannot stand for a long time without deterioration and can transfer the indigenous or contaminated microorganisms to humans due to the absence of cold storage. Lastly, these milk alternatives were historically consumed as

substitutes for animal milk during fasting periods when the consumption of animal products was forbidden [5].

1. **Short-History of Plant Based Milk Alternatives:** The "plant milk" term has a rich history that traces back to ancient Roman times, specifically the fourth century. In Marcus Gavius Apicius' "De re coquinaria," a compilation of Roman Empire cuisine, plant-based milk alternatives were mentioned as common ingredients in the kitchen. The book even uses the term "Lacte Nucis" to refer to hazelnut milk, indicating the practice of extracting milk from various plants and trees. Moving into the medieval period, plant-based milk gained widespread recognition. The Catalan book "Llibre de Sent Sovi" (1324) describes almond milk as a beverage enjoyed by Don Quixote. In England's "The Forme of Cury" (1390), a collection of royal recipes, approximately 45 types of plant milk are mentioned. Nicholas Culpeper's "Whole Herbal" discusses the liver benefits of cucumber milk from a health perspective. Plant-based milk alternatives are also included in recipes found in "Le cuisinier François" (1651) by Pierre de la Varenne in France, Martino's "Neapolitan Collection manuscript" (1470) in Italy, and "Das Buch von guter Speise" (1350) in Germany, demonstrating their use in creating appetizers. The extensive use of plant milk is also documented in Arab culture, such as in the "Book of Dishes" (Kitab al-Tabikh) of Baghdad from the 10th century and the "Anonymous Al- Andalus CookBook" from 1200 AD [5].

   In the modern era, plant-based milk alternatives maintained to evolve and gain popularity in distinct parts of the world. For instance, horchata, originating in Valencia, Spain, became widely available from cities like Madrid to Barcelona. Homemade almond milk was especially popular in Sicily. In Asia, Domingo F. Navarrete's book "A Collection of Voyages and Travels" (1704) mentioned the presence of soy milk in China, Malaysia, and Thailand, often referred to as soy water. In America, the book "Guide for Nut Cookery" written in 1899, documented the use of various plant-based milks, including peanuts, almonds, tiger nuts, cashews, pine nuts, and coconut milk. In South America, the influence of Spanish horchata was evident, and plant-based milk, referred to as horchata, was made using almonds, rice, sesame, and other seeds based on the available products in each country [5]. The modern era witnessed the continuation and diversification of plant-based milk alternatives across different continents, reflecting the cultural and regional preferences of numerous societies.

   The sensitivity of individuals to milk, particularly lactose intolerance, have a significant role in the prevalence and popularity of these milk alternatives worldwide. Lactose intolerance, first reported by Hippocrates around 400 BC, has gained attention in the past 50 years due to the identification of regarding clinical symptoms. Lactose intolerance refers to the inability to digest lactose and affects up to 70% of the global population, with its frequency influenced by ethnic origin. Among adults, individuals of white North European descent, as well as those from North America and Australasia, tend to have the lowest rates of lactose intolerance. For example, the prevalence ranges from 5% in English populations to 17% in northern France and Finland. Otherwise, in regions such as Asia, Africa, and South America, lactase non-persistence affects over 50% of the population, with certain Asian countries even reaching a rate of nearly 100%. Interestingly, individuals of mixed ethnicity generally exhibit a lower diffusiveness of lactase non-persistence compared to the native ethnic groups with high prevalence. The

decrease in lactase activity typically occurs during childhood, although it can also happen later in youth. The decreasing changes in lactase activity rate depending on ethnicity, and the underlying physiological reasons for these timing differences remain unknown. For instance, Japanese and Chinese individuals may experience an 80- 90% decrease in lactase activity in the first 3rd or 4th years after weaning, while Asians and Jews may deceive 60-70% over a couple of years following weaning. In contrast, individuals of white Northern European descent may resume to 18-20 years for the lowest expression of lactase activity [6].

In regions where lactose intolerance is more prevalent, such as certain areas of Asia, Africa, and South America, the consumption of plant-based milk as a substitute for animal sources milk is more common. Plant- based milk provides a lactose-free option for individuals who may experience discomfort or adverse reactions when consuming dairy milk due to lactose intolerance. These plant-based alternatives, derived from sources like soy, almond, coconut, oat, or rice, offer a variety of options to cater to different dietary preferences and needs. They have gained popularity as viable alternatives that provide a similar taste and texture to dairy milk while being free from lactose. The availability and diversity of plant milk products have enlarged in response to the increasing demand for dairy-free options among lactose-intolerant individuals and those following vegan or vegetarian diets.

2. **The Nutrient Profile and Quality of Plant Based Milk Alternatives:** Recently, plants (grains and legumes) have been admitted as functional foods and nutraceuticals due to posing health-promoting constituent such as vitamins, dietary fibers, antioxidants and minerals [7]. In this context, a small number of legumes and oilseeds have begun to be widely used for nutritious, non-animal sources, healthful, purchasable, and plant-based milk alternatives [8].

Plant-based dairy alternatives are beverages that are made by disintegrating and grinding various plant materials, including nuts, legumes, cereals, pseudo-cereals, and oilseeds. These plant raw materials are extracted in water, and this liquid core is homogenized to create liquids that closely resemble the appearance and consistency of cow's milk. The particle size distribution of these alternatives is usually in the of 5 to 20 μm range. While there is no universally defined classification system for these products, they can fall into five main categories according to their raw materials produced: (1) grain group: oat, rice, corn, and spelled milk; (2) Legume group: soy, peanut, lupine, and cowpea milk; (3) nut group: almond, coconut, hazelnut, pistachio, and walnut milk; (4) seed group: sesame, flax, hemp, and sunflower milk; (5) pseudo-cereals groups: quinoa, teff milk, and amaranth milk [9]. These classifications provide a general framework for understanding the different types of plant-based milk alternatives available in the market. The compositional comparison of an example from each category to cow milk has been presented following.

Table 1 provides average values from the United States Department of Agriculture's Food Data Center [10] for the nutritional composition of plant-based milk alternatives. While the exact composition may vary among brands, these values offer a general understanding of their nutrient content compared to cow's milk. In general, grain-based milk alternatives such as rice and oat milk tend to have lower levels of fat and

protein compared to cow's milk. However, they have a higher carbohydrate ratio due to the presence of starch in the grains used. The mineral composition, including calcium and sodium, is similar to cow's milk, although specific values may differ depending on the type of grain used as the raw material. For instance, oat milk has potassium and phosphorus ratios that closely resemble those of cow's milk. Regarding vitamins, cereal-based milk alternatives generally contain comparable amounts to cow's milk. Many plant-based milks are fortified with additional vitamins and minerals to enhance their nutritional value. It's worth noting that the total amount of unsaturated fat in these products can be high, depending on the specific raw material used. Overall, cereal-based milk alternatives provide a different nutritional profile compared to cow's milk, with variations in fat, protein, carbohydrate, mineral, and vitamin content [10,11].

Among legume-based milk alternatives, soy milk is the most commonly known. Soy milk sugarless has alike calorie content to skim cow's milk, making it a suitable choice for individuals looking to manage their calorie intake. Soybeans are nutritionally valuable legumes, and as a result, soy milk derived from this raw material has a composition that is very close to cow's milk in terms of significant minerals and vitamins and protein. The saturated fat content of soy milk is lower than that of cow's milk, which can be advantageous for individuals aiming to reduce their saturated fat intake for cardiovascular health reasons. When deciding between soy milk and cow's milk, individuals should take into account their specific dietary needs and goals. Seeking guidance from a healthcare professional or a registered dietitian can offer personalized advice on choosing the most suitable milk option based on individual preferences and nutritional requirements [10,12]

When looking at the plant-based milk obtained from the nuts-based group, significant differences can be observed in the content of the milk depending on the raw material. For example, while coconut milk lacks protein, hazelnut milk contains a high amount, and cashew milk has about eight times less protein than cow's milk. The fat content also varies proportionally with the tree nut used. Nuts, predominantly rich in saturated fatty acids, have a lower fat content in cashew milk than hazelnut and coconut milk, which have higher fat content than cow's milk. Nutritional fortification for nut-based milk is commonly performed to ensure sufficient minerals and vitamin content. Almost all nut-based milk is typically fortified with calcium, vitamin A, and vitamin D. However, despite the enrichment process, it is significant to note that the bioavailability of nutrients in this milk may not be equivalent to cow's milk nutritionally [10,11].

Flax and hemp milk are part of the group of seed-based milk alternatives. Like other plant-based milk alternatives, seed-based milk is fortified with vitamins A, D, B2, and B12, and minerals such as calcium and phosphorus, to enhance its nutritional value. These milk alternatives have a low carbohydrate and protein content, which can be considered negligible compared to cow's milk. In terms of fat content, flax and hemp milk have lower or comparable levels of fat amount compared to cow's milk. Hemp milk, in particular, is higher in mono- and poly- unsaturated fatty acids than low-fat and fat-free cow's milk. To determine whether specific plant-based milk is fortified, it is significant to examine the nutrition value or ingredient list in label. This information will provide details about the specific nutrients added to the milk [10,11,24].

Quinoa milk is a plant-based milk alternative that belongs to the pseudo-cereal

group. It has approximately half the calories of cow's milk. The majority of its energy comes from the carbohydrates it contains. Quinoa milk has relatively low levels of protein and fat. Like other plant-based milk, it is enriched with vitamins and minerals to enhance its nutritional profile [10,11,12].

Table 1. Nutritional Comparison of Selected Plant-Based Milk Alternatives

Name	Unit	Rice Milk	Oat Milk	Almond Milk	Macadamia Milk	Flax Milk	Hemp Milk	Quinoa Milk	Coconut Milk	Hazelnut Milk	Cashew Milk	Soy Milk	Cow Milk
Energy	kcal	47	50	21	21	10	33	30	183	586	10	43	60
Protein	g	0.28	1.25	0.42	0.42	0	0.83	0.84	0	10.34	0.42	2.6	3.28
Total lipid (fat)	g	0.97	2.08	0.83	2.08	1.04	3.33	0.42	18.3	41.38	0.83	1.47	3.2
Carbohydrate, by difference	g	9.17	6.67	3.33	0.42	0.42	0.42	5.06	3.33	44.83	0.83	4.92	4.67
Fiber, total dietary	g	0.3	0.8	0	0.4	0	0	0	0	3.4	0	0.2	0
Sugars, total including NLEA	g	5.28	2.92	2.92	0	0	0	0.84	1.67	34.48	0	3.65	4.81
Sugars, added	g			2.9									
Calcium, Ca	mg	118	146	54	188	125	125	127	0	207	188	123	123
Iron, Fe	mg	0.2	0.12	0	0.15	0.15	0.45	0.3	0.33	2.48	0.15	0.42	0
Phosphorus, P	mg	56	112			62		25				43	101
Magnesium, Mg	mg	11					17	7			7	15	12
Potassium, K	mg	27	162	11		0	83	46	50		10	122	150
Sodium, Na	mg	39	42	62	40	33	56	46	17	69	67	47	38
Zinc, Zn	mg	0.13		0.42			0.25				0.62	0.26	0.41
Vitamin C	mg	0	0	0	0	0	0	0	0	0	0	0	0
Riboflavin	mg	0.142	0.25				0.177				0.212	0.184	0.138
Vitamin B-12	µg	0.63	0.5		1.25	0.62	0.62				1.25	0.85	0.54
Vitamin A, IU	IU	63		0.25	208	208	208	211		0	208	55	32
Vitamin D (D2 + D3)	IU	1			42	42	42	42	0		42	1.1	1.1
Vitamin E	mcg RE	0.47		3								0.11	0.05
Total saturated fatty acids	g	0	0.21	0	0.42	0	0.21	0	15	15.52	0	0.205	1.86
Total monounsaturated fatty acids	g	0.625		0.42		0	0.42				0.42	0.382	0.688
Total polyunsaturated fatty acids	g	0.313		0		0.62	2.5				0	0.858	0.108
Total trans fatty acids	g		0	0	0	0	0	0	0	0	0		
Cholesterol	mg	0	0	0	0	0	0	0	0	17	0	0	12

Source: USDA [10] “Food Data Central.”; NLEA: Nutrition Labeling and Education Act

II. BIOAVAILIBILITY AND HEALTH EFFECTS

1. **The Potential Health Benefits of Plant Based Milk Alternatives:** Grain-based plant milk alternatives provide reliable option for individuals with cow's milk allergies, as they are generally allergen-free. International labeling regulations require the disclosure of allergenic substances on food labels, and cow's milk contains allergenic proteins. In contrast, grain-based milk alternatives do not contain lactose, making them suitable for individuals with lactose intolerance who want to enjoy milk. These alternatives are low in fat and cholesterol-free, aligning with the recommendations of the Dietary Guidelines for Americans to limit saturated fat intake to less than 10% of daily calories. Reduced-fat cow's milk also adheres to guidelines for reduced calorie intake. When incorporating grain-based plant milk alternatives such as oat milk, rice milk, or grain-based milk into a vegan diet, it is significant for individuals to ensure adequate protein intake from other plant-based sources to meet their nutritional needs. Oat milk particularly contains beta-glucan, fiber type known for its cholesterol-reducing and immune-supporting properties. Consuming oat products, including oats or oat milk, can help lower blood cholesterol levels, positively impact blood sugar and insulin levels, and improve cardiovascular health [12, 13,14].

   Soy milk is the most common of the legume family and offers possible health advantages. First of all, soy milk is rich in essential fatty acids and, thanks to its low saturated fat content, has a reduction effect on the risk of cardiovascular disease. Also, soy milk, considered a complete protein, contains high-quality protein. It contains nine essential amino acids, which is a good source of protein compared to other low-protein plant-based milk. Additionally, soy milk proteins are highly digestible [15]. The isoflavones found in soy milk have been shown to help prevent bone loss and promote bone genesis in menopausal women [16]. In addition, it may have positive effects on visual memory and cognitive function [17]. The higher soy-based product containing isoflavones consumption containing isoflavones is associated with breast [18], prostate [19], colorectal [20], and endometrial cancer [21]. However, it should not be forgotten that soy milk has an allergenic effect. Therefore, it is significant for individuals to consider their allergy status before consuming soy milk.

   Nut-based plant milk can be a suitable alternative for adults allergic to cow's milk or posing lactose intolerance. It is significant to note that the nutritional profile of nut-based milk differs significantly from cow's milk composition. For example, almond and cashew milk contain considerably lower protein than cow milk, and they all are fortified to have higher levels of specific vitamins such as Vitamin A, D, and B12 and calcium [22]. On the other hand, coconut milk has a higher calorie than cow's milk due to its high carbohydrate content [23]. It's significant to consider the potential allergenic properties of nut-based milk, with coconut milk being an exception. Additionally, it's important to note that nut-based milk should not be used as a substitute for breast milk or infant formula. When using them in other contexts, it is crucial to consider individual nutritional needs and, if necessary, consult a healthcare professional.

   Hemp seeds are one of the few plant-based foods that provide all essential amino acids in sufficient levels and are rich in omega-3 fatty acids [24]. Hemp seed oil has been found to make better atopic dermatitis [25], and the high content of arginine amino acid in

hemp seed protein has positive effects on heart health [26]. However, since hemp milk contains a low quantity of hemp seeds, its health benefits may be limited. It can be considered a safe option for those who cannot consume cow's milk due to its non-allergenic nature and absence of lactose.

2. **The Possible Risk of Consuming Plant-Based Milk Alternatives:** Rice milk has a higher glycemic index than cow's milk, which means it cause a higher increase in blood sugar levels after consumption. Diabetic individuals or those at risk of diabetes who need to control their carbohydrate intake and blood sugar levels may find that rice milk is not the most suitable option for these people. One potential health concern associated with rice milk is the presence of high amounts of arsenic [27]. Arsenic is a poisoner and toxic metal inherently found in water and soil and can pass to food through plants. Rice tends to absorb higher levels of arsenic than other grains, and if not properly monitored, it can reach unsafe levels. The Food and Drug Administration (FDA) conducts food examinations to ensure consumers' limited exposure to this metal from rice and other food sources in the USA [28]. Therefore, commercially available rice milk in the United States is accepted to contain low levels of arsenic. However, moderate consumption is still recommended, including rice and rice-containing products.

   Soy milk may interrelate with specific medications, particularly warfarin, reducing their effectiveness [29]. Individuals should consult their doctors or pharmacists for more information on possible interactions between soy milk and medications. Additionally, it is significant to be aware that soybean is one of the eight primary food allergens identified by the FDA. Therefore, individuals with soy allergies should avoid consuming soy milk. While oats are not considered a common food allergen [30], oat milk allergies are possible. However, the potential disadvantage of oat milk consumption is higher total carbohydrate content per serving than cow's milk. Among specific populations like elderly adults, replacing cow's milk with a plant-based milk may result in inadequate protein intake.

   Additionally, it is significant to note that tree nuts like almonds are sometimes a common cause of severe or life-threatening allergic reactions. Almonds contain various proteins, including protein amandin (AMP). Unlike other plant proteins, amandin does not denature or break down during heat processing. This effect makes almond milk a suitable alternative for individuals with a tree nut allergy, specifically to peanuts. Almond milk is labeled as a product containing allergens in accordance with the Food Allergen Labeling and Consumer Protection Act (FALCPA). Cashew milk can pose a potential risk for individuals with allergies as it contains known food allergens such as cashews and almonds. It is crucial for allergic individuals to exercise caution when consuming cashew milk or products containing cashews or almonds [31].

   The low protein content of cashew milk is another significant consideration for specific groups like elderly adults and vegans who may already struggle to meet their protein needs. Adequate protein intake is necessary for various body functions, including muscle building and preservation [32]. Consumption of coconut milk has potential disadvantages due to its high saturated fat content, especially compared to other plant-based milk alternatives. The Dietary Guidelines for Americans suggest a restrictive daily calorie intake of less than 10% saturated fats to diminish cardiovascular disease risk [33].

One downside of hemp milk is its low protein level. Therefore, individuals who choose hemp milk as a substitute for cow's milk should ensure they obtain sufficient protein from other sources or consider adding protein powders such as soy or pea protein to their hemp milk.

3. **Bioavailability and Digestibility of Plant-Based Milk Alternatives:** The quality of protein is defined as its essential amino acid content, digestibility, and bioavailability of digested amino acids. When it comes to plant-based beverages, such as those made from grains, nuts, seeds, and legumes, they generally have lower nutritional values compared to meat and animal products. Because plant-based products tend to have higher proportions of components like fiber, vitamins C and E, folic acid, magnesium, phytochemicals, and polyunsaturated fatty acids, on the other hand, they contain lower amounts of cholesterol, total and saturated fats, and protein. The plant-based and animal protein sources have different bioavailability in total protein intake and essential amino acid profile. Therefore, individuals following a plant-based diet ensure they have an appropriate diet program that allows for the intake of all essential amino acids and also the other 20 amino acids found in plant proteins [34].

   As it is known, amino acids play a vital role in the functioning of many body processes [35]. Therefore, it is emphasized the necessity of determining the bioavailability of amino acids, which refers to the absorbable and utilizable amino acids by the body. The Food and Agriculture Organization (FAO) has developed the Protein Digestibility Corrected Amino Acid Score (PDCAAS) scoring system to assess protein quality [36,37]. However, due to the bacterial metabolism of amino acids in the intestine, which can misleadingly increase the values of actual protein digestibility, FAO has proposed a new scoring system called Digestible Indispensable Amino Acid Score (DIAAS) to replace PDCAAS in measuring protein quality [38]. These two systems demonstrate the bioavailability of amino acids, but there are differences in their calculations. Another significant difference between the two measuring systems is that PDCAAS is based on digestion in the large intestine, whereas DIAAS focuses on the digestion in the end part of the small intestine called the ileum [39,40].

   Protein quality refers to the essential amino acid amount and bioavailability in a protein source. When examining animal protein sources, milk, eggs, and meat proteins have a PDCAAS (Protein Digestibility Corrected Amino Acid Score) value of 1.00 or very close [38, 41]. However, other plant-based beverages used in production, such as quinoa, have a PDCAAS value of 0.78, rice 0.5, and peanuts 0.46. This difference indicates that animal proteins are considered complete protein sources as they meet the essential amino acid requirements throughout human life. While soybeans have amino acid amounts similar to milk, other plant proteins may be poor in bioavailability. For example, legumes often have low levels of sulfur amino acids, specifically methionine and cysteine, and grains have low lysine content [42].

   Determining the composition of food products is crucial for calculating their energy content, establishing production parameters, and understanding their overall nutritional value. However, it is significant that this data does not fully reflect the metabolic effect or bioavailability of the food item [43]. Bioavailability provides insights into the nutritional quality of food and can influence the metabolic reactions of

consuming that food. In other words, even if two foods have the same composition, their utilization, metabolic, and physiological effects on the body can differ. Plant proteins have lower bioaccessibility and bioavailability compared to animal proteins. While studies on this topic primarily focus on protein quality, concerns have also been raised about similar effects on the bioavailability of vitamins and minerals. Because most plant proteins generally contain substances like phytic acid that can impede the absorption of zinc, manganese, iron, and calcium. The presence of dietary fiber and antinutrients (such as tannins, phytic acid, saponins, etc.) in plant-based foods forms a barrier against digestion, and limits access to nutrients during digestion, resulting in lower bioavailability compared to animal-based foods [44]. Animal proteins contain higher bioactive peptides and have better protein digestibility [45]. However, by applying various processing methods to plant proteins (such as heat, fermentation, soaking, mechanical processing, irradiation, etc.), antinutrients can be altered in structure and function, thereby increasing the bioavailability of vitamins and minerals [44]. According to the scoring system prepared by FAO for evaluating protein quality, the bioavailability of plant-based proteins is estimated to be between 51-92%, while for animal proteins, this value ranges from 90-95% [46]. It is known that plant-based milk alternatives made from grains, nuts, legumes, and seeds have lower protein content compared to their raw materials. Overall, the lower digestibility and bioavailability of plant proteins compared to animal proteins result in a lower bioavailability of proteins in plant-based milk alternatives. In conclusion, plant-based milk alternatives generally have lower protein, mineral, and vitamin content than animal milk. Furthermore, the bioavailability of these components is also lower in plant-based alternatives compared to animal milk.

III. FACTORS SUPPORTING THE GROWTH OF PLANT-BASED MILK ALTERNATIVE MARKET SHARE

The trend of consumers using organic and vegan products increases the popularity of plant-based milk alternatives. Strategic Market Research reveals that the global plant-based milk market will witness a strong 15% Annual Average Growth Rate (CAGR) of $35 billion in 2021 and will increase in value to $123.1 billion by 2030. North America had a substantial market share of over 40% in 2021 [47]. The coronavirus pandemic caused people to reevaluate their diets with the crisis it created in food and health issues, as in other areas, and unexpected increases in the plant-based dairy industry. With the outbreak of COVID-19, the need for personnel in the production of animal products and the less labor dependency on agricultural products have led to a rise in plant-based milk demand. In addition, medical research has also revealed the trend that plant-based milk will reduce these problems, as COVID-19 negatively impacts the health of people such as diabetes, hypertension, and heart disease from being sedentary at home [48]. The factors that are efficient in increasing the market share of these products and the concerns they create in people's minds are given below.

1. **Environmental Sustainability:** The production of plant-based milk alternatives is known to have a lower environmental impact compared to animal-based products. This concern is a key factor that attracts environmentally conscious consumers concerned about sustainability. Plant-based options have lower greenhouse gas emissions and require less water throughout their production process. As a result, the combination of veganism and environmental awareness has led to a significant increase in the adoption of plant-based

meat and milk alternatives [49]. These choices align with intending to reduce the ecological footprint associated with food production and contribute to a more sustainable and environmentally friendly food system.

2. **Increasing Lactose Intolerance:** The increasing prevalence of lactose intolerance in societies has led to growing consumer demand for plant-based dairy alternatives. Lactose intolerance can occur in various forms, with primary lactose intolerance being the most common. This form occurs naturally as individuals age and experiences a decrease in lactase production. Secondary lactose intolerance can arise from certain medical conditions or treatments that damage the small intestine, such as celiac disease or chemotherapy. Congenital lactose intolerance is a rare genetic disorder from birth, while developmental lactose intolerance may occur in premature infants.

   The correlation between intestine diseases and lactose intolerance has contributed to the retail growth of lactose-free products, lactase supplements, and related treatments. As the prevalence of intestine diseases increases, there is a higher demand for these specialized products catering to individuals with lactose intolerance. Government and health organizations often recommend lactose-free milk or plant-based dairy products as convenient alternatives for individuals with lactose intolerance.

   However, it is significant to note that some plant-based milk alternatives may have lower nutritional value than traditional dairy milk. Additionally, potential labeling issues can pose challenges to the consumption of plant-based milk alternatives, despite their popularity. Addressing these concerns and ensuring accurate labeling can help overcome these challenges and further drive the market for lactose-free and plant-based products [48].

3. **Growing Demand for Plant-Based Foods:** The younger generations, specifically Generation Y and Generation Z have shown a growing interest in sustainable and healthy food choices, leading to an increased demand for plant-based alternatives to traditional staple food products. This trend is particularly notable in the preference for plant-based milk alternatives. The demand for plant-based protein sources, driven by concerns for environmental sustainability and personal health, has played a significant role in this shift.

   Additionally, the rising popularity of veganism, especially among Generation Y, has created a substantial consumer base for plant-based milk alternatives [50]. These younger generations are actively seeking out food options that align with their values, including ethical and sustainable practices, and are driving the growth of the plant-based food industry.

4. **Nutritional Considerations:** Plant-based milk alternatives typically have lower fat and protein content than animal milk. However, there are efforts to create the perception that these alternatives, especially soy milk, have similar or even higher protein content to enhance their sales potential. It is significant for consumers to be aware of the nutritional differences and consider supplementing their diets with additional nutrients when using plant-based milk alternatives.

   Furthermore, it is worth noting that some plant-based milk alternatives may

contain additives and added sugars, despite the perception of natural or organic characteristics. These factors should be taken into consideration when making purchasing decisions [9,50]. Consumers are encouraged to read product labels and choose options that align with their dietary needs and preferences.

5. **Strengthening Distribution through Online Retail Channels:** The emergence of e-commerce has expanded the market reach for food and beverage products, including plant-based milk alternatives. Online platforms, shopping sites, and various online sales channels have played a crucial role in facilitating the distribution and availability of these products. Consumers can now conveniently purchase plant-based milk alternatives from the comfort of their own homes, increasing accessibility and choice. The ease of online shopping has contributed to the growth and popularity of plant-based milk alternatives in the market [47].

6. **Anticipated Market Growth for Flavored Products:** The growing utilization of flavoring substances in food formulation is anticipated to propel the market expansion of flavored plant-based milk alternatives. Natural and dairy-free milk flavors play an important role in addressing taste and texture limitations, enhancing the overall sensory experience, and accelerating product commercialization. By incorporating these flavors, manufacturers can enhance the palatability of plant-based milk alternatives, making them more appealing to consumers. This trend is expected to contribute to the continued growth and diversification of the plant-based milk market [47,50].

7. **Growing Interest in Plant-Based Dairy Alternatives and Veganism:** Plant-based milk alternatives provide numerous nutritional benefits and are particularly sought after by consumers seeking cholesterol-free options that promote cardiovascular health and help control diabetes. Soy milk, for instance, is known for its rich content of omega-3 fatty acids, protein, fiber, and isoflavones, which offer therapeutic properties. Furthermore, the availability of low-calorie and vitamin-fortified alternatives appeals to health-conscious individuals. However, it is worth noting that allergenic concerns, particularly related to soy and other plant-based milk alternatives, may have an impact on the growth of the market [47]. Despite this potential limitation, the overall demand for plant-based milk alternatives remains strong due to their appealing nutritional profile and the increasing focus on health and wellness among consumers.

8. **Changes in Consumer Lifestyles and Business Opportunities:** The global population growth and the challenges posed by resource scarcity have intensified the pressure on food resources. Additionally, the rising energy and raw material costs have a direct impact on low-income consumers. In response to them, consumer preferences have shifted towards natural and healthier food options. This choise presents a significant opportunity for plant-based milk alternatives to meet the growing demand for sustainable and nutritious alternatives to traditional dairy products.

The trend towards plant-based milk alternatives is expected to be particularly prominent in Asia Pacific countries with high rates of lactose intolerance. These regions provide a favorable market environment for emerging economies to capitalize on the increasing demand for plant-based alternatives. By offering products that cater to lactose-intolerant individuals and align with the preferences for natural and healthier options,

plant-based milk alternatives have the potential for substantial growth in these markets [47]. This issue presents an opportunity for established players and emerging brands to tap into the evolving consumer needs and preferences in the Asia Pacific region.

9. **Low Consumer Awareness:** One of the challenges facing the growth of the milk alternatives market is the lack of awareness regarding the nutritional benefits of these products. Some consumers perceive plant-based milk alternatives to have significantly lower nutritional value than cow's milk. While it is true that plant-based milk alternatives generally have lower protein content, efforts are made to fortify these products and enhance their overall nutritional value [48]. Increasing awareness among consumers about the benefits of milk alternatives will be crucial for market expansion. Educating consumers about the nutritional composition of plant-based milk alternatives, highlighting their positive attributes, such as being cholesterol-free, lower in saturated fats, and rich in vitamins and minerals, can help overcome misconceptions and build confidence in these products. Additionally, emphasizing the various fortification techniques used to enhance the nutritional profile of milk alternatives can further address concerns related to lower protein content. Marketing campaigns, educational initiatives, and partnerships with healthcare professionals and nutritionists can play a significant role in awareness and promoting the nutritional benefits of plant-based milk alternatives. By providing accurate information and dispelling misconceptions, the market for milk alternatives can expand and attract a broader consumer base.

IV. CONCERNS ABOUT ANIMAL MILK

1. **Allergic Reactions in Infants:** Milk allergies are estimated to affect 2-3% of infants, although most children tend to outgrow this allergy by six. It is significant to recognize that infants have specific nutritional needs. And if they cannot consume breast milk, it is advisable to seek guidance from a healthcare professional or registered dietitian. They can provide appropriate recommendations to ensure that infants' nutritional requirements are compensated by suitable protein sources supported by plant-based milk alternatives or other options.

   Furthermore, it is crucial to be aware that soy milk is among the top eight food allergens, which can limit the market for plant-based milk alternatives that contain allergenic ingredients. This problem highlights the importance of considering individual allergies and sensitivities when selecting the most suitable milk alternative for infants and individuals with specific dietary requirements [51,52]. Consulting with healthcare professionals can help navigate these considerations and ensure the safety and suitability of plant-based milk alternatives for individuals with allergies or specific nutritional needs.

2. **Negative Impact on Health with Lactose Intolerance:** Lactose intolerance prevalence varies across populations, with higher rates commonly observed in South America, Africa, and Asia. Lactose intolerance refers to the inability to fully digest lactose, the sugar found in milk and dairy products, leading to gastrointestinal discomfort after consuming milk. While lactose-free milk is an option for individuals with lactose intolerance, people prefer non-dairy alternatives.

   This preference has contributed to the increased consumption of plant-based milk

options. Plant-based beverage alternatives, such as almond milk, soy milk, and oat milk, offer lactose-intolerant individuals a dairy- free alternative that can be easily incorporated into their diets. This shift towards plant-based milk alternatives is driven by the desire to avoid gastrointestinal discomfort associated with lactose intolerance and the increasing availability of diverse and appealing plant-based options in the market [50]. The availability of these alternatives provides lactose-intolerant individuals with an extensive range of choices that align with their dietary preferences and needs.

3. **Environmental Concerns:** Animal agriculture, including dairy production, has been associated with damaging effects on the environment's sustainability. It is recognized as a contributor to water consumption, greenhouse gas emissions, and land use. Specifically, dairy cattle contribute to greenhouse gas emissions, mainly through methane production, and require substantial resources such as water and land.

   In contrast, producing milk alternatives from plant-based sources is generally considered a more sustainable and environmentally friendly practice. Plant-based milk alternatives have a lower environmental impact by water consumption, greenhouse gas emissions, and land use than traditional dairy production [49]. By changing diets to plant-based milk alternatives, individuals' ecological footprint can reduce, and they contribute to more sustainable food systems. This awareness of the environmental consequences of animal agriculture has fueled the growing interest and adoption of plant-based milk alternatives to promote sustainability and mitigate the environmental impact of food production.

4. **Presence of Antibiotics and Pesticides in Milk:** Consumers are really concerned about the presence of antibiotics and pesticides in milk, which can arise from conventional dairy production practices. Antibiotics may be treated in dairy animals for various reasons, including disease prevention and treatment, but there is a risk of residues remaining in the milk. Pesticides can also find their way into milk through animal feed or environmental contamination.

   Organic milk production offers an alternative to managing chemical problems. Organic milk is produced without antibiotics or synthetic pesticides by eliminating the risk of these substances being present in the final product. Organic farming practices prioritize natural methods and emphasize the well-being of animals and environmental sustainability.

   However, it's worth noting that organic products, including organic milk, tend to be more expensive than their conventional counterparts. This pricing difference can limit accessibility for some consumers, making organic products a less viable option for particular individuals [53]. Nevertheless, for consumers who prioritize avoiding antibiotics and pesticide residues in their dairy products, organic milk provides an option that aligns with their concerns for food safety and sustainability.

5. **Effects on Prostate Health, Bone Health, and Hormones:** Some studies have suggested a potential link between high dairy consumption and an increased risk of prostate cancer in men. These studies have led to recommendations to reduce dairy intake as a precautionary measure [54,55]. However, it is significant to note that the evidence

regarding this association is not definitive, and further research is needed to fully understand the relationship between dairy consumption and prostate cancer risk.

The studies have yielded mixed results regarding the effects of milk on bone health. While milk is believed to be beneficial for bone health due to its calcium content, some research has raised questions about its protective role against osteoporosis and fractures [56,57]. These conflicting findings highlight the complexity of the relationship between milk consumption and bone health, and additional studies are required to provide more conclusive evidence.

There have been concerns about the presence of hormones, such as estrogen and progesterone, in milk and their potential impact on cancer risk and early puberty in girls. However, the available evidence supporting these concerns is limited [58,59]. More research is necessary to fully understand the potential effects of hormones in milk on human health.

It is significant to approach these findings with awareness and consider the overall balance of a varied and balanced diet when making dietary choices. Consulting with healthcare professionals or registered dietitians can provide personalized guidance based on individual health conditions and concerns.

V. CONCERNS ABOUT PLANT-BASED MILK ALTERNATIVES

1. **Nutritional Deficiencies:** Plant-based milk alternatives may have apparent differences in nutritional composition compared to animal milk. While they can serve as a good source of certain nutrients, such as calcium and vitamin D (when fortified), they may be lower in protein than cow's milk. It is significant for individuals, especially children who rely on plant-based milk alternatives, to provide a well-rounded and balanced diet to meet their nutritional needs. Protein is an essential macronutrient that plays a vital role in various bodily functions, including growth, development, and repair. If children rely on plant-based milk alternatives as their primary source of milk, it is significant to obtain adequate protein from plant-based sources such as legumes, nuts, seeds, tofu, and other plant- based protein-rich foods. Incorporating diverse protein sources into their diet can help compensate for potentialprotein deficiencies.

   Additionally, individuals consuming plant-based milk alternatives should pay attention to their diet and ensure they meet their nutritional requirements for other essential nutrients, such as vitamins, minerals, and fats. Consulting with a healthcare professional or registered dietitian can provide personalized guidance to ensure that individuals consuming plant-based milk alternatives have a well-balanced and nutritious diet that meets their physiological needs [60].

2. **Higher Prices:** Plant-based milk alternatives can indeed be more expensive compared to animal milk. The pricing of these alternatives is affected by various factors, including the cost of raw materials, production processes, and market demand. Plant-based milk alternatives from materials such as legumes or nuts tend to be priced higher due to the higher costs associated with sourcing and processing these ingredients.

However, as the market for plant-based alternatives continues to grow and gain popularity, there is potential for economies of scale and increased competition to drive down prices. As more consumers opt for plant- based options and demand increases, manufacturers may be able to optimize their production processes and negotiate better pricing for raw materials, leading to more affordable options in the future.

Moreover, progress and innovation in the plant-based food industry may contribute to cost reductions over time. As production methods become more efficient and ingredients become more readily available, the prices of plant-based milk alternatives may become more competitive with animal milk.

It is worth noting that the prices of plant-based milk alternatives can vary depending on brands, geographical locations, and specific product characteristics. Comparing different options and exploring local markets can help individuals find more affordable plant-based milk alternatives that suit their preferences and budgets [50].

3. **Use of Fillers:** Some plant-based milk alternatives may contain additives to enhance their sensory properties, improve nutritional value, or extend shelf life. These additives include acidity regulators, flavorings, stabilizers, sweeteners, and dyes. While some additives are used to provide beneficial characteristics, such as fortifying the product with vitamins or adding dietary fiber, excessive or unnecessary use of additives can raise concerns among consumers. Excessive use of additives may impact the perceived naturalness and purity of the product. Consumers often prefer products with simple ingredient lists and fewer artificial additives.

   Many manufacturers strive to create plant-based milk alternatives with minimal and clean ingredient lists. There is an increasing demand for products free from artificial additives and closer to their natural state. Consumers are seeking options with recognizable and familiar ingredients.

   When choosing plant-based milk alternatives, individuals can review the ingredient list and opt for products that align with their preferences for minimal additives. Additionally, seeking out organic or certified products may provide assurance that fewer artificial additives are used in the manufacturing process.

   As consumer demand continues to shape the market, manufacturers increasingly respond by developing plant-based milk alternatives that meet the desire for cleaner and more natural products [61].

4. **Added Sugars:** Considering the importance of providing healthier options, some manufacturers have responded by introducing plant-based milk alternatives free from added sugars. These unsweetened varieties offer consumers a choice that aligns with their preferences for reducing sugar intake.

   Unsweetened plant-based milk alternatives can still provide a creamy and satisfying taste without added sugars. Many individuals find these a suitable choice, whether for dietary reasons or to reduce overall sugar consumption. It's important to note that even unsweetened plant-based milk alternatives may naturally contain some sugar

from the original plant source, such as oats or almonds.

Reading product labels and choosing unsweetened or minimally sweetened plant-based milk alternatives can be a wise approach for those mindful of their sugar intake. It allows individuals to have more control over the amount of added sugars in their diet while still enjoying the benefits of plant-based milk alternatives.

As consumer demand for healthier options continues to grow, more varieties of plant-based milk alternatives without added sugars will likely become available in the market [61].

VI. CONCLUSION

Developing suitable processing methods and formulations, ensuring product quality and safety, and enriching the nutritional content are crucial considerations for food manufacturers entering the plant-based milk market. Meeting consumer expectations in terms of sensory properties, taste, aroma, and texture is essential to drive customer satisfaction and acceptance of these products. Fortifying plant-based milk alternatives with essential nutrients like dietary fiber, vitamins, amino acids, and oils can enhance their nutritional value and provide a well-rounded alternative to animal milk. This is important to address any potential nutritional deficiencies and meet the dietary needs of consumers. From a commercial perspective, understanding consumer trends and preferences is vital. The increasing interest in natural and traditional products, the popularity of plant-based alternatives among the younger generation, and the growing adoption of veganism and environmental consciousness all contribute to the rising demand for plant-based food sources, including plant-based milk. By prioritizing product quality, nutritional enrichment, and aligning with consumer preferences, manufacturers can effectively compete in the plant-based milk market and cater to the diverse needs of consumers. These innovations will also contribute to their business success and support the overall growth and development of the plant-based food industry.

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