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A comparative review of dairy and plant-based milks in modern diets

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Abstract

As people become more health-conscious and environmentally aware, the demand for plant-based milk alternatives has risen significantly. This review explores the growth of the plant-based milk market, comparing it to traditional dairy milk in terms of nutrition, health benefits, and environmental impact. While plant-based milks like soy, almond, and oat are free from cholesterol and offer health benefits such as disease prevention, they often need added nutrients like calcium and vitamin D to match the nutritional profile of dairy milk. Dairy milk, on the other hand, is rich in essential nutrients but is less suitable for those with lactose intolerance or concerns about milk fats and environmental impact. In terms of sustainability, plant-based milks generally have a lower environmental footprint, producing fewer greenhouse gases and using less water than dairy milk, although options like almond milk have been criticized for their high water usage. Taste, texture, and sweetness are important factors in consumer acceptance, with many preferring plant-based milks that mimic dairy milk closely. Despite some drawbacks, such as lower nutrient density and taste variations, plant-based milks are seen as a healthier and more eco-friendly option, reflecting a shift in consumer preferences toward more sustainable and nutritious food choices. This review highlights the growing role of plant-based milks in meeting the demand for better alternatives that benefit both health and the planet.

Keywords: Plant-based milk, dairy milk, environmental impact, sustainability, lactose intolerance

1. Introduction

In recent years, public awareness about health and nutrition has significantly increased. People are now more inclined to choose foods that not only nourish but also offer additional health benefits, such as preventing chronic diseases and supporting healthy aging (Egea *et al.*, 2023) ^[18]. This growing interest has fueled the rise of plant-based foods and beverages, which are becoming popular due to dietary preferences, environmental concerns, and ethical considerations (Egea *et al.*, 2022) ^[19].

The plant-based food market is experiencing remarkable growth. Projections suggest it will grow from USD 30 billion in 2023 to USD 160 billion by 2030, showcasing a strong demand for innovative alternatives (Bloomberg, 2021) ^[6]. Among these options, plant-based milk has gained significant attention, particularly among people who are lactose intolerant or allergic to cow's milk. Moreover, plant-

based milk options typically have a smaller environmental footprint, requiring less water and producing fewer greenhouse gases compared to traditional dairy farming (Lemes *et al.*, 2020; Lemes *et al.*, 2022) ^[32, 19].

However, developing plant-based milk that is nutritionally comparable to cow's milk, while also being appealing in taste and texture, remains a challenge (Chalupa-Krebzdak *et al.*, 2018) ^[10]. Despite the popularity of cow's milk, it has limitations. Cow's milk is known for its rich nutrient profile, including fats, proteins, carbohydrates, and essential micronutrients like calcium, vitamin B12, and selenium, which contribute to overall health (Plant-Based Foods Association, 2016; Mäkinen *et al.*, 2016) ^[3, 33]. Yet, it lacks certain essential minerals and is unsuitable for those with lactose intolerance, especially elderly individuals. Additionally, concerns about cholesterol, coupled with the rise of veganism, have led to increased interest in plant-

based milk alternatives (Vanga & Raghavan, 2018) ^[57]. Plant-based milk is derived from legumes, cereals, and oilseeds. These alternatives are not only nutritious but also have a lower environmental impact compared to dairy milk. Studies show that plant-based milk can reduce the risk of cardiovascular diseases and improve immune function, making it especially popular in Western and European markets (Grant & Hicks, 2018) ^[25]. Furthermore, traditional methods like fermentation can enhance the quality and nutritional value of these alternatives, positioning them as a healthy and sustainable choice (Sharma, Joshi, & Abrol, 2012) ^[50].

Globally, milk consumption remains high, with many countries promoting its regular intake. For example, Austria recommends three servings of milk daily to meet nutrient requirements (Rozenberg *et al.*, 2016) ^[47]. Nevertheless, the environmental impact of dairy production is a significant concern. Issues like soil degradation, water pollution, and biodiversity loss have drawn attention (Centre for European Agricultural Studies). In fact, food and beverage consumption contributes to about one-third of the total environmental impact of households in EU countries, emphasizing the need for sustainable alternatives (European Environmental Agency).

This study focuses on exploring new combinations of plant-based ingredients as substitutes for cow's milk. It aims to evaluate their properties and overall potential to meet the growing demand for healthier and more sustainable food options.

2. Plant milk vs Regular dairy milk

Plant-based milks are beverages made from plant extracts that mimic the texture and appearance of cow's milk. They are typically made by extracting flavours and nutrients from

plants like soy, almonds, oats, and coconuts, and then mixing them with water. These drinks are particularly popular among vegans, as well as people with lactose intolerance or milk allergies (McClements DJ, 2019) ^[34]. In addition to being a dietary choice, plant-based milks are increasingly favoured for their lower environmental impact compared to traditional dairy milk (Paul AA *et al.*, 2020) ^[2]. While plant-based milks are often fortified with essential nutrients like calcium and vitamins A and D to improve their nutritional value, they generally have lower nutrient density compared to dairy milk (Vanga SK, Raghavan V., 2018; Bridges M., 2018) ^[57, 8]. To improve flavour and texture, manufacturers sometimes add sugars and thickeners, so it's important for consumers to check the nutritional labels to make sure they're choosing the best option for their health (Jeske *et al.*, 2018) ^[28].

Dairy milk, on the other hand, is a well-rounded source of nutrition. It contains important macronutrients like fats, proteins, and carbohydrates, as well as micronutrients such as calcium, selenium, riboflavin, and vitamins B and B5 (Das A *et al.*, 2012) ^[14]. Dairy milk plays a key role in hydration, nourishment, and supporting the immune system in new-born mammals (Murphy *et al.*, 2017) ^[39]. Fermented dairy products, like yogurt, offer additional benefits for people with lactose intolerance, as they contain bacterial lactase, which helps break down lactose (Kolars *et al.*, 1984) ^[29]. Despite its strong nutritional profile, some people avoid dairy milk due to lactose intolerance, milk allergies, or concerns about heart health related to the fat in milk (Murphy *et al.*, 2017) ^[39]. Additionally, the environmental impact of dairy production and ethical concerns around animal welfare often encourage individuals to choose plant-based alternatives (Paul AA *et al.*, 2020) ^[2].

Table 1: Nutritional content of fortified cow, soy, almond and oat milks (wikipedia-2020) ^[58]

Nutrient value per 250 mL cup	Cow milk (whole)	Soy milk (unsweetened)	Almond milk (unsweetened)	Oat milk (unsweetened)
Energy, kJ (kcal)	620 (149)	330(80)	160(39)	500(120)
Protein (g)	7.69	6.95	1.55	3
Fat (g)	7.93	3.91	2.88	5
Saturated fat (g)	4.55	0.5	0	0.5
Carbohydrate (g)	11.71	4.23	1.52	16
Fiber (g)	0	1.2	0	2
Sugars (g)	12.32	1	0	7
Calcium (mg)	276	301	516	350
Potassium (mg)	322	292	176	390
Sodium (mg)	105	90	186	140
Vitamin B12 (µg)	1.10	2.70	0	1.2
Vitamin A (IU)	395	503	372	267
Vitamin D (IU)	124	119	110	144
Cholesterol (mg)	24	0	0	0

3. Health Benefits and Drawbacks of Dairy Milk

Health Benefits

1. **Nutrient-Rich:** Dairy milk is considered a complete food, offering a rich blend of essential nutrients that promote bone health, hydration, and gut microflora development (Murphy *et al.*, 2017) ^[39].
2. **Fermented Dairy for Lactose Intolerance:** Fermented dairy products like yogurt are beneficial for lactose-intolerant individuals because they have reduced lactose levels and contain bacterial lactase, aiding digestion

(Kolars *et al.*, 1984) ^[29].

3. **Fortified Options for Lactose Intolerance:** Fortified dairy products can also help people with lactose intolerance by adding the lactase enzyme, which breaks down lactose and reduces discomfort (USDA, 2007).
4. **No Added Sugars:** Dairy milk contains lactose naturally, but it doesn't have any added sugars, making it a healthier choice for people watching their sugar intake compared to some plant-based milks (Jeske *et al.*, 2018) ^[28].

Drawbacks

1. **Fat and Heart Health:** Dairy milk contains fat, which has been linked to heart disease, making some people look for alternatives (Murphy *et al.*, 2017) ^[39].
2. **Lactose Intolerance:** While fermented dairy products can help, dairy milk still contains lactose, which can be problematic for individuals who are lactose intolerant, although fortified options with lactase help mitigate this issue (USDA, 2007).

4. Health Benefits and Drawbacks of Plant-Based Milk Health Benefits

1. **Cholesterol-Free:** Plant-based milks are naturally cholesterol-free, making them a heart-healthy alternative to dairy milk (Vanga SK, Raghavan V., 2018) ^[57].
2. **Fortified with Essential Nutrients:** Many plant-based milks are fortified with important nutrients like calcium, vitamin D, and vitamin B12, which are crucial for maintaining bone health (Vanga SK, Raghavan V., 2018) ^[57].
3. **Immune Boosting and Weight Support:** Coconut milk contains lauric acid, which is thought to boost the immune system, and medium-chain triglycerides (MCTs), which may help with weight loss and energy (McClements DJ, 2019) ^[34].
4. **Good for Disease Prevention:** Soy, almond, and oat milks are packed with antioxidants, fiber, and vitamins, all of which can help prevent chronic diseases (Jeske *et al.*, 2018; Cortés *et al.*, 2005) ^[28, 13].
5. **Promotes Overall Health:** Plant-based milks are increasingly considered functional foods, meaning they have health benefits like helping with obesity and supporting heart health (Sethi S *et al.*, 2016) ^[49].

Drawback

1. **Added Sugars and Fillers:** Many plant-based milks come with added sugars and stabilizers to improve taste and texture. It's best to look for unsweetened or minimally processed versions to avoid these additives (Paul AA *et al.*, 2020) ^[2].
2. **Not as Nutrient-Dense:** While plant-based milks offer some health benefits, they tend to be less nutrient-dense than dairy milk, often requiring fortification to match dairy's nutritional value (Vanga SK, Raghavan V., 2018) ^[57].

5. Environmental and Ethical Consideration

Dairy farming significantly impacts the environment, particularly regarding greenhouse gas emissions (GHGe) and water usage. It is highly resource-intensive, contributing substantially to global GHGe, which are often much higher than those linked to plant-based foods (Gerber PJ *et al.*, 2013; Xu X *et al.*, 2021; Mekonnen MM and Gerbens-Leenes W., 2020) ^[24, 59, 36]. Studies, including life cycle assessments, reveal that the median GHGe per liter for plant-based milks such as soy, oat, almond, spelt, pea, and coconut is 62–78% lower than those for cow's milk.

Water usage adds another layer of complexity. While plant-based milks generally require less water to produce than cow's milk, almond milk stands out with the highest water consumption per unit, especially in regions experiencing

water scarcity. Despite this, options like oat and soy milk often outperform dairy milk in various environmental metrics, including land use and acidification (Geburt K *et al.*, 2022) ^[23].

Dairy farming has made strides in efficiency, reducing land use, but it still raises concerns about public health, ecological impact, and animal welfare (Clay N *et al.*, 2020) ^[12]. In contrast, plant-based milks usually present a lower environmental burden. However, the environmental impact varies by product and region, requiring further research to evaluate these differences comprehensively. The environmental footprint of dairy farming stems from its resource demands, including water for livestock and feed crops, and its contribution to climate change through high GHGe. Consumers increasingly seek alternatives like plant-based milks due to sustainability concerns. These alternatives, such as soy, oat, and almond milk, generally produce fewer greenhouse gases and consume less water, making them more eco-friendly options for many (Sethi S and Tyagi SK., 2016; Clara Guibourg and Helen Briggs, 2019; Franklin-Wallis O., 2019; FAO Soymilk and related products, 2019) ^[49, 11, 22, 21].

However, some plant-based milks face scrutiny. Almond milk, for example, is often criticized for its significant water usage and pesticide reliance. Environmental footprints, including emissions, land use, and water requirements, vary among plant milks based on farming practices and crop needs. Still, their overall environmental impact remains lower than that of dairy milk, primarily due to reduced energy demands per unit produced (Sethi S and Tyagi SK., 2016) ^[49].

While plant-based milks are seen as more sustainable, they are not without challenges. This underscores the importance of carefully evaluating production processes and practices to minimize environmental burdens (Paul AA *et al.*, 2020; Das A *et al.*, 2012) ^[2, 14].

Table 2: Mean greenhouse gas emissions for one glass (200 g) of different milks (Guibourg & Briggs, 2019) ^[11]

Milk Types	Greenhouse Gas Emission (kg CO ₂ -Ceq per 200 g)
Cow's Milk	0.62
Rice Milk	0.23
Soy Milk	0.21
Oat Milk	0.19
Almond Milk	0.16

6. Consumer Preferences

6.1 Market Trends and Growth

The popularity of plant-based dairy alternatives (PBDA) has grown tremendously in recent years. These alternatives now account for 7.4% of the total milk market, and this share is projected to more than double, reaching 18.5% by 2023 (Mintel Group Ltd., 2019a) ^[38]. Meanwhile, traditional dairy milk, particularly fluid milk, has been on a steady decline, with sales dropping by 15% since 2012 (Mintel Group Ltd., 2019a) ^[38]. Interestingly, more than half of dairy milk consumers are also buying PBDA, indicating that people are incorporating both plant-based and dairy products into their diets (Baertlein, 2015; Mintel Group Ltd., 2019a) ^[4, 38]. This shift was evident in 2018 when sales of plant-based milks rose by 9%, while cow's milk sales dropped by 6% (Plant-

Based Foods Association, 2018). These trends reflect a clear change in consumer habits, with people looking for a wider variety of beverage options that align with their lifestyle and preferences.

6.2 Sensory Attributes and Consumer Acceptance

The taste and texture of plant-based milks play a crucial role in whether consumers like them. Each type of plant-based milk has a unique flavour profile that comes from its plant source (Vaikma *et al.*, 2021) ^[56]. Cereal-Based Milks (like oat, rice, buckwheat, and quinoa) tend to have a cereal-like flavour. Oat-based milks often have a bitter aftertaste. Buckwheat and quinoa-based milks are sweeter. Rice milk stands out for its astringent taste and hay-like smell, which some people dislike. Nut-Based Milks (like almond, cashew, coconut, and Brazil nut) are thicker in texture, which many consumers prefer. Cashew and Brazil nut milks also have umami flavors, while almond milk has a nutty and sometimes salty taste. Soy and Hemp-Based milks have strong astringent flavors and earthy or hay-like smells. Soy milk in particular may have a metallic undertone and a reddish tint (Vaikma *et al.*, 2021) ^[56].

6.3 Consumer Challenges and Preferences

Consumers tend to prefer plant-based milks that closely resemble dairy milk in terms of flavour, texture, and sweetness. Those with unconventional or strong flavors—like metallic, nutty, or astringent notes are often less accepted (Diarra *et al.*, 2005; Sakthi *et al.*, 2020; Oduro *et al.*, 2021) ^[16, 48, 41].

Texture is especially important. Nut-based milks are often favoured for their thicker consistency, which provides a satisfying mouthfeel. On the other hand, rice-based milks are often criticized for being too thin, which lowers their appeal. Researchers suggest that improving the thickness of rice-based milks could make them more popular (Pramudya *et al.*, 2019) ^[44]. Similarly, the level of sweetness plays a big role in consumer preference. Finding the right balance of sweetness is crucial, as some products are either too sweet or not sweet enough (Pramudya *et al.*, 2019) ^[44].

7. Conclusion

The growing shift toward plant-based milks reflects changing consumer preferences, driven by health, sustainability, and ethical concerns. While dairy milk remains a valuable source of essential nutrients, issues like lactose intolerance, health risks related to milk fat, and the environmental impact of dairy farming are pushing more people to explore alternatives. Plant-based milks, despite some nutritional gaps and taste variations, offer a promising solution with fewer environmental drawbacks. As the market continues to evolve, plant-based milks are likely to play an even larger role in meeting the demands of health-conscious and eco-conscious consumers.

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