International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Vegan Paneer– A Dairy-Free Alternative

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Received: 27 Mar 2025; Received in revised form: 25 Apr 2025; Accepted: 02 May 2025; Available online: 07 May 2025

Abstract— *As more people look for healthier and eco-friendly food choices, vegan paneer is becoming a popular alternative to traditional dairy paneer. This review takes a closer look at why vegan paneer is gaining traction, touching on its nutritional benefits, market trends, and the growing demand from people with lactose intolerance and dairy allergies. The world market, worth about $9 billion in 2022, is expected to expand significantly, with India's market to reach INR 1848 billion by 2032. The demand for plant-based alternatives is also on the rise, as seen in the $270 million sales of non-dairy cheese in the US in 2020.Vegan paneer comes in various forms, including soy-based, nut-based, and millet-based options, each with unique flavors and textures. While it offers benefits like lower cholesterol and being allergen-free, one of the main challenges is achieving the same taste and texture as dairy paneer. There are also concerns about nutritional gaps, making fortification an essential part of product development. Innovation is key to making plant-based alternatives more appealing and accessible. As the industry evolves, the focus remains on creating delicious, nutritious, and sustainable vegan paneer options that meet consumer expectations and contribute to a better food future.*

Keywords— ***Vegan paneer, dairy alternatives, nutritional benefits, market dynamics, lactose intolerance, plant-based diets, sustainability.***

I. INTRODUCTION

Dairy products are popular for their nutritional value and appealing flavours, offering fat, protein, vitamins, and calcium [1]. However, changing dietary habits, particularly in developed countries, have increased demand for sustainable, plant-based alternatives. This shift is driven by health, ethical reasons, and concerns over dairy's environmental impact, including greenhouse gas emissions contributing to global warming.Rising dairy costs have further spurred research into casein and fat replacements, aiming to create dairy-free products with comparable sensory and functional qualities[2].

Paneer is a highly nutritious and affordable source of animal protein, making it a staple for many vegetarians. This soft, unripened cheese is widely consumed in South Asia and is made by heating the milk and curdling it with an acid. Unlike some other cheeses, paneer is unaged, does not melt, and is non-fermentative. Nutritionally, paneer is rich in fat (around 26%) and protein (around 21%), with a biological protein value between 80 and 86. It also contains a small amount of lactose (around 3%) and ash (about 1.9%) [3]. These properties make it a valuable protein source, particularly for individuals following a vegetarian diet.

Vegan paneer is a dairy-free alternative to traditional paneer, created for people who follow a vegan diet, are lactose-intolerant, or want a more eco-friendly food option. It is made to resemble regular paneer in texture, taste, and nutrition while using plant-based ingredients instead of milk. Unlike dairy paneer, vegan versions are made from ingredients like soy, almonds, cashews, or even newer options like coconut and millet milk. These plant-based choices help achieve the soft, crumbly texture of traditional paneer while offering added health benefits,

such as lower cholesterol and being free from common allergens [4].

Researchers have also explored making a groundnut-based dehydrated version of vegan paneer, designed to be a convenient, high-protein option [5].

1.1 Size of the Traditional Paneer Market Globally and in India

1.1.1 Global market

In 2022, the world paneer market was to be at $9.4 billion, and it is predicted to keep expanding. The growing demand for paneer can be linked to various factors, such as population growth, shifting dietary habits, a rising interest in ethnic cuisines, and its inclusion in western fast-food menus [6].

1.1.2 Indian market

According to the latest reports from the IMARC , the market in India was valued at INR 570.8 billion in 2023 [6]. It is projected to grow significantly, reaching INR 1848.9 billion by 2032, with a compound annual growth rate (CAGR) of 13.95% between 2023 and 2032.Curdled dairy products such as paneer, chenna, and sandesh are highly favoured by the Indian population. Among these, paneer stands out as the most popular, accounting for about 5% of the total milk produced in India [7].

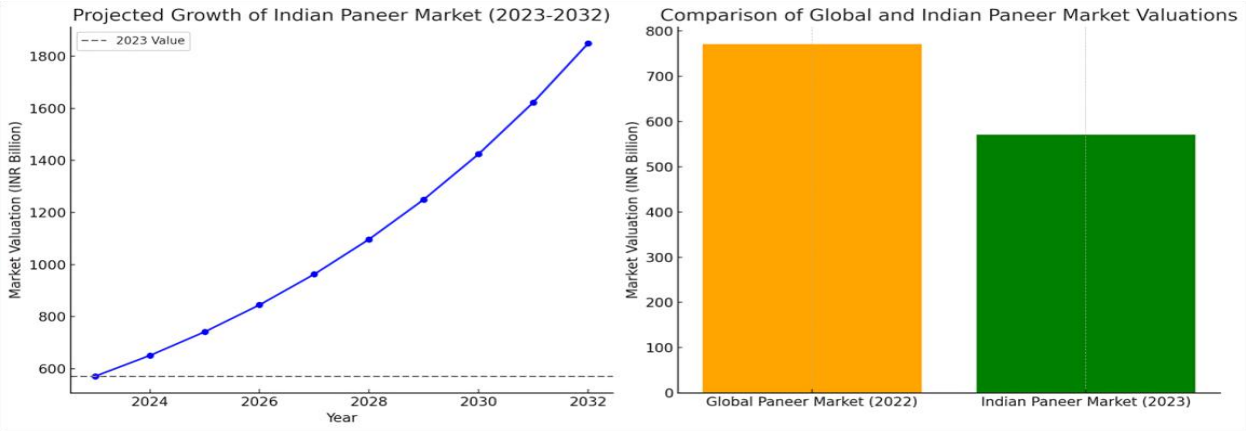

Fig.1: Size of the Traditional Paneer Market Globally and in India

1.2 Size of vegan alternatives market

The demand for cheese alternatives is rising quickly, especially among vegans and people who are lactose intolerant [8]. However, creating a plant-based cheese that matches the taste, texture, and meltability of traditional dairy cheese remains a major challenge. Some industry experts even consider it "almost impossible" [9]. In 2020, sales of non-dairy cheese in the US hit $270 million, a 42.5% jump from 2019 [10]. This rapid growth has made plant-based cheese one of the fastest-expanding area in the plant-based food industry [2]. Looking ahead, the vegan cheese market is expected to grow by nearly 12% between 2021 and 2028 [6].

The dairy substitute market has been one of the fastest-growing industries in recent years. Plant-based beverages are now more popular than dairy milk, largely because they are free from lactose and cholesterol [9]. The increasing demand for plant-based milk alternatives is driven by several factors, including a rise in cow milk allergies, lactose intolerance, high cholesterol levels, and a growing preference for vegetarian and plant-based diets. As a result, a variety of veganbased milks, such as soy milk, almond milk, and oat milkhave entered the market as dairy substitutes. These alternatives are becoming more widely accepted, with plant-based milk sales increasing by 20% in 2020. That year, dairy milk's annual revenue growth was half that of plant-based milk. By 2020, plant-based milk held a 15% share of the retail market in most households, and experts predict that nearly 40% of homes will adopt these products in the future [8].

1.3 Consumer preferences of Dairy paneer in India

A survey of 500 people in India on dairy paneer consumption found that 32% eat paneer two to three times a month, while only 4% consume it daily, suggesting that paneer is not a staple for most households. Additionally, one in four respondents buy paneer regularly, indicating that purchases are generally infrequent. Many consumers are skeptical about the quality, freshness, and taste of branded paneer, often preferring local vendors who are believed to offer fresher options. Interestingly, 17% of respondents have never tried branded paneer, pointing to a lack of trial purchases and emphasizing the need for better marketing strategies [11].

This article provides an in-depth look at the rising demand for vegan paneer as a healthy and eco-friendly alternative to traditional dairy paneer. It explores the nutritional

benefits of paneer, market trends for both dairy and plant-based options, and the growing shift toward plant-based diets. The discussion covers both the advantages and challenges of vegan paneer, including its suitability for people with lactose intolerance or dairy allergies, while also addressing concerns about nutritional deficiencies and the need for fortification. It also examines different types of vegan paneer, such as soy-based, nut-based, and millet-based varieties, focusing on their texture, taste, and functional properties. Ultimately, the article highlights the need for continuous innovation in developing plant-based paneer options that meet consumer expectations and support a more sustainable food system.

II. NEED FOR VEGAN PANEER

2.1 Lactose Intolerance and Milk Allergies

Allergies to cow's milk, eggs, wheat, and soy often fade during childhood, whereas allergies to tree nuts, peanuts, and seafood are more likely to last a lifetime [12]. Since cow's milk is introduced early in life, it is one of the first foods that can cause allergic reactions. The two most common issues linked to cow's milk consumption arecow's milk allergyand lactose intolerance[8].

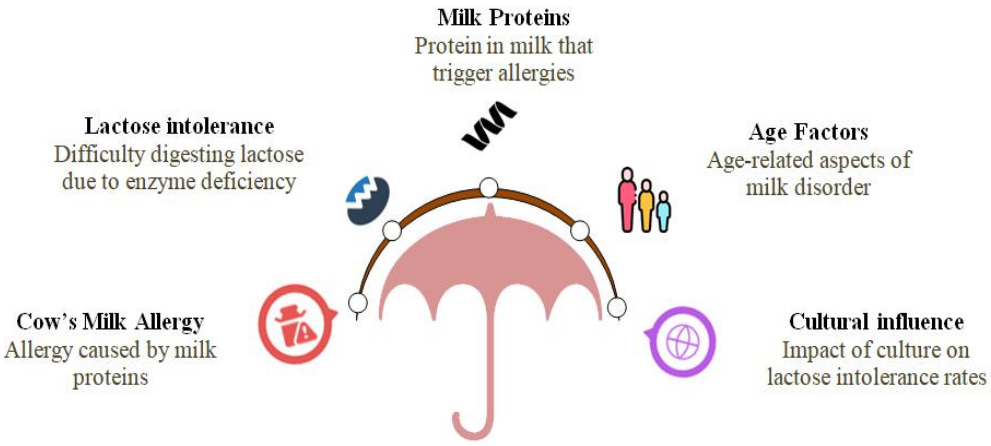

Fig.2: Understanding of lactose intolerance and dairy allergies

Allergies occur when the immune system mistakenly sees a harmless food antigen as a threat, triggering a defensive reaction after consumption. In case of cow's milk allergy. The body's immune system identifies and reacts to certain milk proteins, such as casein, β-lactoglobulin, α-lactalbumin, serum albumin, and immunoglobulins [13]. Lactose intolerance, on the other hand, is a digestive condition that affects people of all ages. It happens when the body lacks enough lactase, the enzyme needed to break down lactose—the main carbohydrate in milk. This leads to symptoms associated with lactose maldigestion, as lactose makes up 2% to 8% of the solid portion of milk [14]. Lactose is a disaccharide made of glucose and galactose, serving as an energy source. While mammals, including humans, are born with the ability to digest lactose, about 75% of the global population develops lactose intolerance, with adult prevalence remaining under 20% [15]. Populations with a history of dairy consumption tend to have lower rates of lactose intolerance than those relying more on agriculture [16]. Infants and older adults are more prone to lactose intolerance, although newborns usually produce enough lactase [17]. Temporary intolerance can occur in children after intestinal infections or food allergies, as these conditions reduce lactase production. Recovery may take weeks or months, during which lactose-containing foods may be poorly tolerated. A natural decline in lactase production starts around ages 3 to 6, and in some cases, it ceases entirely. Symptoms of lactose intolerance typically appear during adolescence or early adulthood [17].

2.2 Health Trends

People who follow vegetarian diets tend to be more health-conscious, have a leaner body composition, and often enjoy better overall health compared to those who eat both plant and animal foods. However, these differences may also mean that vegetarians naturally have fewer risk factors for certain health conditions, which could affect how research findings apply to the general population. This might lead to an overestimation of the health benefits of vegetarian diets. Within plant-based diets, the vegan lifestyle—eliminating all animal-derived products—has become increasingly popular. While some studies suggest that a vegan diet offers health benefits, the evidence is still not entirely conclusive [18].

2.3 Adulteration of traditional paneer

The issue of adulterated paneer, especially those made with unsaturated vegetable fats, is becoming a major food safety and public health concern. To cut costs and extend shelf life, some manufacturers use cheaper and potentially harmful substitutes like unsaturated vegetable fats or synthetic oils [19]. While these additives help keep paneer soft and fresh for longer, they pose serious health risks.The dangers of consuming adulterated paneer go beyond immediate digestive problems like nausea, vomiting, and diarrhea[20]. Over time, these harmful ingredients can contribute to severe health issues such as liver and kidney damage, heart disease, weakened immunity, and even developmental delays in children. Raising consumer awareness and implementing stricter regulations are essential to ensuring the safety and quality of paneer available in the market [21].

2.4 Sustainability

Plant-based diets offer substantial environmental benefits, such as decreased resource utilization, minimized greenhouse gas emissions, and enhanced biodiversity compared to animal-based diets [22]. Shifting toward predominantly plant-based eating habits could play a crucial role in addressing climate change and ensuring global food security for a growing population. However, there are still challenges to overcome. These include the environmental impact of large-scale monoculture farming, emissions from transporting plant-based products, and socioeconomic factors like affordability and accessibility [23]. Addressing these issues is essential to making plant-based diets a truly sustainable and viable solution for the future.

III. DIFFERENT TYPES OF VEGAN PANEER PRODUCTS

3.1 Soy-based paneer

Tofu, commonly known as soy-based paneer, has been extensively studied for its nutritional advantages and potential as a dairy-free alternative. Researchers have explored the use of soy protein isolate (SPI) to enhance the nutritional profile of paneer while reducing fat content. Findings suggest that adding SPI boosts yield, protein, ash, and moisture levels while lowering fat and calorie intake. However, exceeding 0.2% SPI led to an undesirable beany taste, which negatively impacted its overall acceptability [24].

Another study focused on producing soy paneer by combining soymilk and buffalo milk in a 70:30 ratio, using 2% acetic acid for coagulation. The results indicated that this blend improved the texture and nutritional value of soy paneer, making it a more affordable and healthy option [25].

Further research examined different proportions of toned milk and soymilk (80:20, 70:30, 60:40) to determine the ideal combination for enhancing both taste and nutrition. The study revealed that certain blends significantly improved the sensory appeal and health benefits of soy paneer, positioning it as a plant-based alternative to milk paneer [26].

3.2 Nut-Based Paneer

Nut-based substitutes for traditional dairy paneer have been extensively researched developed a quick-to-prepare paneer alternative from peanuts using microwave dehydration. The process involved soaking, removing the skin, grinding, extracting milk, and coagulating with calcium salts. The final product closely mimicked conventional paneer in texture and taste, highlighting the potential of peanuts as a plant-based alternative [27].

Mounsey and O'Riordan explored the use of different nuts, such as peanuts, cashews, macadamias, and almonds, in producing non-dairy cheese and paneer substitutes. These nut-based alternatives provide a nutritious and flexible option for individuals with dietary restrictions, allergies, or those following a plant-based lifestyle, expanding choices beyond traditional dairy products [9].

3.3 Millet-Based Paneer

Incorporation of Millet Flours into Paneer: Narayananstudied the impact of adding 1% wheat and finger millet (ragi) flours to paneer to boost its fiber content. The findings indicated that the millet-enhanced paneer maintained similar flavor and overall acceptability compared to regular paneer [28].

Development of Millet-Blended Paneer Kheer: Kumar et al. developed a fiber-rich paneer kheer by incorporating foxtail millet (Setariaitalica) flour at varying levels (2%, 3%, and 4%). The study determined that 2% millet flour provided the best sensory experience, enhancing texture, consistency, and imparting a nutty flavor [29].

Optimization of Coagulants in Millet Paneer Production**:** Singh et al. analyzed how different food-grade acids—citric, tartaric, and malic acids—affected the texture and sensory properties of Kodo millet (Paspalum scrobiculatum) paneer. The results showed that higher acid concentrations negatively influenced both texture and taste, emphasizing the need for careful coagulant selection to maintain product quality [30].

IV. PROTEIN AND FAT QUALITY OF MILK AND PLANT BASED SOURCES

The quality of a dietary protein depends on how well it meets the body's need for essential amino acids. This includes the amino acid composition of the protein as well as how efficiently the body can digest, absorb, and utilize it [31]. One common way to measure protein quality is assessed using the Protein Digestibility Corrected Amino Acid Score (PDCAAS), which measures how well a protein meets essential amino acid needs. This score considers both the protein's amino acid composition and its digestibility. A score below 100% indicates that the protein does not fully meet the body's amino acid needs. Most plant-based proteins tested so far have scores below 100%, meaning they are generally less complete compared to animal proteins. For instance, wheat gluten has a particularly low PDCAAS score of just 25%, making it one of the least effective plant proteins in providing essential amino acids[32].

Table 1: Protein and fat quality of milk and plant based sources

Source	Protein	Protein Digestibility (%)	PDCAAS	DIAAS	Fat	Reference
Animal source						
Milk	3.2	96	100	114	4.1	[32]
Plant source						
Soy	43.2	98	100	-	19.7	[33]
Green lentil	25.1	84	63	65	0.7	[32]
Yellow split pea	24.5	88	64	73	1.2	[32]
Green pea	7.2	99	89	58	1.6	[34]
Chickpea	17.1	89	74	82	5.3	[32]
Oilseeds source						
Peanuts	25.3	-	52	-	40	[32]
Coconut	3.4	-	-	-	41	[34]

V. PROPERTIES OF DAIRY AND VEGAN PANEER

5.1 Physicochemical properties

Physicochemical properties refer to the physical and chemical attributes of food materials that impact their behavior during processing, storage, and consumption [35].

5.1.1Texture Profile Analysis (TPA)

Texture Profile Analysis (TPA) is a widely used method for evaluating the textural qualities of food products, including paneer. This technique provides a quantitative assessment of various textural parameters, which are crucial for determining quality, consumer acceptance, and culinary applications. Typically, a texture analyzer measures properties such as resilience, gumminess, chewiness, cohesiveness, hardness, and springiness [36].

Table 2: Texture profile analysis of dairy and vegan paneer

	Firmness (g)	Stickiness (g mm)	Elasticity (mm)	Binding capacity	Toughness (g)	Masticability (g mm)
Milk Paneer	3221 ± 59d	−22.4 ± 4.8a	0.47 ± 0.03c	0.42 ± 0.02d	1416 ± 58d	657 ± 21e
Pea paneer	1096 ± 23a	−4.32 ± 1.5c	0.21 ± 0.01a	0.22 ± 0.01a	332 ± 27a	93 ± 6a
Tofu	1375 ±82c	-	4.90 ± 0.23 b	0.71 ± 0.01 b	998.00 ± 28d	4809.75 ± 35.5
Reference : [37, 38]						

5.1.2 Bulk density

Bulk density is a crucial physicochemical property of paneer that affects its texture, quality, and overall consumer acceptance. It is defined as the mass per unit volume of paneer and is typically expressed in grams per cubic centimeter (g/cc). This property plays a significant role in determining the firmness and mouthfeel of paneer, influencing its suitability for various culinary applications [39].

Table 3: Bulk density analysis of dairy paneer

Pressure (kg/cm^2)	Pressing Duration (min)	Bulk Density (g/cc)
3.0	10	1.03
3.0	15	1.08
4.0	10	1.05
4.0	15	1.07
5.0	10	1.10
5.0	15	1.36
Reference: [40]		

5.2 Functional Attributes

Vegan paneer exhibits distinct functional properties compared to dairy paneer due to differences in protein structure. These variations influence key attributes such as heat resistance and moisture retention. Water holding capacity impacts the texture and juiciness of the final product, influencing its ability to retain moisture during preparation. These factors play a crucial role in shaping the sensory and culinary performance of vegan paneer in various dishes [40].

VI. CHALLENGES OF VEGAN PANEER

The rising consumer demand for dairy-free cheese alternatives, driven by health benefits and market trends, has attracted significant entrepreneurial interest. However, achieving broad acceptance remains a challenge [41]. Key efforts must focus on educating consumers about the benefits of these products, addressing concerns about taste and quality, and refining formulations to replicate the sensory attributes of traditional cheese. One major hurdle is replicating the desired texture and flavor, as plant-based proteins often impact sensory appeal. This highlights the importance of continued research and innovation to enhance mouthfeel, texture, and overall consumer experience [2]. Researchers are exploring novel formulations and processing techniques to overcome these challenges. By improving the sensory qualities of dairy-free cheese using innovative plant-based ingredients, manufacturers can better align with consumer expectations, boosting market adoption and investment in this growing sector [38].

VII. ADVANTAGES AND DISADVANTAGES OF VEGAN PANEER

Advantages
Numerous studies indicate that a vegan diet can significantly lower the risk of conditions like cardiovascular diseases, obesity, and certain cancers. Long-term adherence promotes overall health [6].
Diets based on plants can enhance blood sugar regulation and improve insulin sensitivity,making them beneficial for diabetes management and individuals with metabolic syndrome [6].
Plant-based diets often utilize fewer environmental resources, reducing the ecological footprint compared to animal agriculture and supporting ethical considerations in food choices [6].
Legumes provide high protein content, fiber, and essential nutrients, and their digestibility can be enhanced through methods like sprouting and fermenting [23].
Fortified plant-based milks offer vital nutrients like calcium, vitamin D, and vitamin B12, and they serve as good dairy alternatives. Varieties like soy and oat milk replicatedairy in flavor and functionality [23].
Disadvantages
Vegan paneer lacks specific proteins and lipids that aid in calcium absorption, which may lead to decreased bone mineral density if not properly fortified with calcium and vitamin D [42].
Essential components such as vitamin B12 and omega-3 fatty acids are often less available in vegan sources, necessitating supplementation or careful dietary planning to prevent deficiencies [43].
The iron content in plant-based sources can be less available for absorption, which may increase the risk of iron deficiency anemia unless paired with vitamin C-rich foods or fortified products to enhance absorption [43].

VIII. POSSIBLE BY PRODUCTS

8.1 Mung bean paneer

The development of hybrid dairy-legume cheese substitutes involves the partial replacement of dairy proteins with legume-based alternatives. This approach offers enhanced nutritional and functional benefits while promoting the creation of more sustainable food products. It also has the potential to expand market opportunities by catering to diverse consumer preferences. A recent study explored the use of plant proteins as a base for developing flavoured cheese with a sensory profile tailored to the tastes of Southeast and East Asian consumers [44]. The research suggested that incorporating proteins commonly found in regional diets could enhance flavour familiarity and acceptance, making these products more appealing [45].

8.2 Coconut milk-based paneer

Current research trends in novel product development are largely influenced by increasing urbanization, which has driven demand for specialty and functional beverages. The physico-chemical, sensory, and nutritional properties of coconut milk and its derivatives, such as coconut yogurt and coconut-based paneer, closely resemble those of cow's milk products.

Derived from a fruit rich in fiber, vitamin C, and essential minerals, coconut milk is naturally lactose-free and contains easily digestible medium-chain triglycerides (MCTs) that support weight management. Additionally, coconut milk has been linked to increased high-density lipoprotein (HDL) cholesterol, which benefits cardiovascular health. Its lauric acid content also exhibits antibacterial, antiviral, and anti-inflammatory properties [46].

8.3 Synbiotic millet paneer

Synbiotic millet paneer is an innovative dairy alternative designed to improve both nutritional value and gut health [50]. A study by [46] explored the production of this paneer by fermenting millet flour with specific probiotic strains, resulting in a product that not only mimics the texture of traditional paneer but also provides the health benefits of probiotics. The study emphasized that millet, a gluten-free grain, is rich in essential nutrients such as

vitamins, fiber, and protein, making it suitable for individuals with dietary restrictions. Additionally, the inclusion of probiotics in the fermentation process supports a healthy gut microbiome, potentially enhancing digestive health. This novel product offers a versatile ingredient for various culinary applications, appealing to health-conscious consumers seeking sustainable food choices [44].

8.4 Millet milk-based powder

The millet milk powder developed in this invention is composed of sucrose, millet, honey, and fresh milk[47]. Its primary benefits include a calorie content of 383 kcal[48] and a carbohydrate content of 78%, making it nutritionally comparable to dairy milk[49]. It also contains 0.9% crude fiber, which is higher than that of dairy milk but lower than coconut milk [50]. Additionally, it has a higher protein content (7-8%) and fat content (0.6–0.7%)[51]. The study found that when stored at low temperatures, the viscosity of millet milk decreases while total soluble solids increase[52]. Drum-dried millet milk was observed to have a high protein content of 8.57%, whereas malted millet milk was characterized by lower fat and higher fiber and protein level [47].

8.5 Fermented millet milk beverage

[48] developed a fermented beverage by blending skim milk with millet milk in three different ratios (25:75, 50:50, and 75:25). The millets were first sprouted separately and then combined with the milk mixture. A 2% starter culture was added, and the mixture was heated at 37°C for 12 hours to facilitate fermentation. During this period, the milk was left undisturbed to ensure proper curdling. Once fermentation was complete, the curd was blended using an electric mixer, with salt and spices added as needed. The study also evaluated consumer perception based on different millet and skim milk combinations. More recently, [49,50] examined the nutritional, physical, and organoleptic properties of millet-based milk following malting. The kodo millet-based milk beverage contained 1.75 g of protein, 15 °Brix TSS, 0.86 acidity, 3.26 g of total sugar, 5.73 g of starch, and 1.79 g of reducing sugar per 100 g. The study found that sprouting millet reduced viscosity and sedimentation while enhancing milk yield [53].

IX. CONCLUSION

Vegan paneer presents a promising alternative to traditional dairy products, but several challenges hinder its widespread adoption. One of the primary obstacles is replicating the sensory qualities of dairy paneer, as differences in taste and texture often lead to consumer skepticism. Nutritional gaps, particularly in essential proteins, vitamin B12, and omega-3 fatty acids, further complicate its suitability as a sole dietary option, necessitating careful supplementation and dietary planning. Additionally, while plant-based diets are generally more sustainable, concerns arise regarding the environmental impact of monoculture farming and the carbon footprint associated with ingredient sourcing and transportation. These factors must be critically assessed to ensure that the ecological benefits of vegan paneer outweigh its drawbacks. The market for vegan paneer also faces intense competition from various dairy alternatives, making consumer engagement and market penetration more challenging. To address these limitations, innovative formulations, fortification strategies, and sustainable agricultural practices are essential. Ongoing research and development efforts should focus on enhancing vegan paneer's nutritional profile and sensory attributes to align with consumer expectations. Furthermore, increasing consumer education and awareness about the benefits and potential of plant-based alternatives will be crucial for their broader acceptance in mainstream diets.

ACKNOWLEDGEMENT

The authors are grateful to the Department of Food Technology and Research Department(Seed money project) , Ramaiah University of Applied Sciences, Bengaluru, India.

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