Lab-Grown Milk: Opportunities and Challenges for India

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ABSTRACT

The global dairy sector is undergoing a transformative shift with the emergence of lab-grown milk, produced via precision fermentation. Unlike plant-based alternatives, lab-grown milk replicates the exact proteins found in cow's milk—casein and whey—without involving animals. This technology offers sustainable, ethical, and climate-friendly solutions, with the potential to reduce greenhouse gas emissions, land use, and water consumption. Globally, start-ups such as Perfect Day, Remilk, and TurtleTree are pioneering fermentation-derived dairy, securing regulatory approvals in the US, Singapore, and Israel. For India, the world's largest milk producer, lab-grown milk presents both opportunities and challenges: it can reduce imports of whey protein, create high-value protein markets, promote biotech entrepreneurship, and complement traditional dairying. Key challenges include regulatory clarity, consumer acceptance, technology costs, and protection of smallholder livelihoods. Strategic policy support, public-private partnerships, and investment in indigenous biotechnology are critical to the integration of lab-grown milk into India's dairy sector. A balanced approach can enable India to harness innovation while safeguarding cultural traditions and rural economies, positioning the country as a global leader in sustainable dairy.

INTRODUCTION

Over the last few decades, the global dairy sector has witnessed tremendous transformation—from traditional dairying to intensive production systems, value-added products, and digital innovations in milk processing. Today, the industry stands at the verge of yet another disruptive shift: the emergence of lab-grown milk produced through precision fermentation. Unlike plant-based beverages, lab-grown milk aims to replicate the exact proteins found in bovine milk (especially casein and whey), but without involving animals.

This technology is gaining momentum as consumer demand for sustainable, ethical, and climate-friendly foods rises. For a country like India—the world's largest milk producer and home to 80 million dairy farmers—the introduction of lab-grown milk raises important questions. Is it a threat or an opportunity? Can it support India's nutritional security? How will it affect rural livelihoods? This article examines the scientific basis of lab-grown milk, global trends, opportunities for India, challenges, and a future roadmap for integrating this innovation into the Indian dairy sector.

What Exactly is Lab-Grown Milk?

Lab-grown milk (also known as fermentation-derived milk proteins or animal-free dairy) is produced using microorganisms such as yeast, fungi, or microalgae. Scientists modify these microbes to express dairy proteins—primarily casein and whey—which are then purified and combined with water, fats, sugars, vitamins, and minerals to recreate the characteristics of cow's milk.

Key points:

- It is not plant-based milk (like almond or soy).
- It contains real milk proteins identical to cow's milk at the molecular level.
- It is lactose-free if manufacturers choose to remove or replace lactose.
- It does not require cows, land for fodder, or antibiotics.

The result is a product that behaves like milk in terms of taste, functionality, and nutrition—making it suitable for the manufacture of cheese, yogurt, ice cream, and high-protein beverages.

Global Landscape and Developments

Purba & Sangsawad (2025) list companies actively working on fermentation-derived dairy products. Some leading innovators include:

- **Perfect Day (USA)** – The first to commercialize fermentation-derived whey protein; used in ice creams, chocolates, and protein powders.
- **Remilk (Israel)** – Focuses on large-scale casein production for cheese manufacturing.
- **Imagindairy (Israel)** – Working on cost-effective fermentation for mass adoption.
- **Formo (Germany)** – Specialized in cheese made from precision-fermentation casein.

Regulatory approvals

Countries such as the USA, Singapore, and Israel have granted preliminary approvals for specific fermentation-derived dairy proteins. The European Union and the UK are currently reviewing safety dossiers. In the US, Perfect Day® offers ice cream manufactured from non-animal proteins synthesized by bioengineered bacteria. Solar Foods, a Finnish

firm, has acquired market approval in Singapore for its Solein single-cell protein. ReMilk, an Israeli startup, has recently received regulatory approval in Singapore and a "No Questions Letter" from the FDA for its animal-free milk protein derived from genetically modified microbes. Currently, no EU country has approved cellular agriculture-derived dairy proteins for use in food products (Fytsilis *et al*., 2024).

Perfect Day introduced its animal-free dairy proteins to the market in 2020, which served as the foundation for a number of goods, including ice cream, cream cheese, and milk. These products, developed in collaboration with food manufacturers and merchants, have received significant recognition for their ability to replicate the flavour, texture, and functionality of traditional dairy, offering consumers a sustainable and ethical option. Unilever and Nestlé have begun adding Perfect Day's whey protein to their product lines over the past two years, representing a significant step in the adoption of precision fermentation technology.

In 2022, under the Approval for Non-Specified Food and Food Ingredients Regulations, the FSSAI granted prior (pre-market) approval to two alternative protein products: mycoprotein derived from *Fusarium venenatum* and Perfect Day's non-animal whey protein produced through precision fermentation. In 2023, the FSSAI further expanded this category by approving Reliance's algal protein powder, developed via biomass fermentation, under the same NSF Regulation.

In November 2023, TurtleTree reached a major milestone by obtaining the world's first Self-GRAS (Generally Recognised as Safe) status for animal-free lactoferrin, officially clearing the way for commercialisation in the U.S. This approval allowed TurtleTree to bring its precision-fermented lactoferrin to market, marking a significant advancement in functional dairy protein production.

Market projection

According to recent market analysis of DATA INTELO, the global Precision Fermentation Dairy Market is valued at USD 2.14 billion in 2024, reflecting the rapid rise of animal-free dairy proteins across international food systems. The sector is expanding at an exceptional pace, with a projected CAGR of 41.2% between 2025 and 2033. By 2033, the market is expected to reach USD 40.19 billion, driven by ongoing technological innovation, growing consumer preference for sustainable foods, and a growing shift toward alternative protein sources. This remarkable growth trajectory underscores the strong commercial potential of precision-fermented milk proteins and their emerging role in the global dairy industry.

How Lab-Grown Milk Is Produced?

To understand how artificial milk is created, scientists generally follow two technological pathways.

1. **Bottom-up**: The bottom-up approach starts by breaking milk into its smallest molecular components, producing each component individually, then blending them back together. This method offers remarkable control over what goes into the final product, but it often falls short in recreating milk's natural structural complexity.

2. **Top-up**: The top-down approach, on the other hand, uses whole cellular systems to imitate the biological process of lactation. This helps preserve the intricate architecture of real milk but provides less freedom to modify individual components.

3. **Precision Fermentation**: Bridging these two approaches is precision fermentation, the technology that currently underpins

most commercial advances in animal-free dairy. Here, genetically engineered microorganisms act as miniature factories, producing milk proteins that are structurally identical to those found in cow's milk—while still allowing manufacturers to fine-tune the final formulation. Thanks to this unique balance of authenticity and flexibility, precision fermentation has become the preferred route for innovators, with nearly 76% of artificial-milk ventures worldwide adopting this approach (Purba & Sangsawad, 2025).

Comparison with Traditional Milk

Microbially produced milk proteins are molecularly identical to cow's casein and whey, while offering customizable fat and carbohydrate profiles. This enables the development of lactose-free and cholesterol-free formulations. Functionally, these proteins replicate the melting, stretching, coagulation, foaming, and emulsifying properties of conventional dairy proteins, supporting applications in cheese, yogurt, and nutritional supplements. They can also be fortified with omega-3 fatty acids, vitamin D, calcium, and magnesium, broadening their nutritional scope.

Government Support for Precision Fermentation Technology in India

Smart protein products in India are likely to be regulated under the Food Safety and Standards (Approval of Non-Specified Food and Food Ingredients) Regulations, 2017 (NSF Regulations). Foods without a history of human consumption or created using novel technologies—such as cultivated meat and precision/biomass fermentation products—are treated as non-specified or novel foods. Manufacturers or importers must submit detailed applications, along with supporting documents, to the FSSAI before these products can be manufactured or marketed.

In December 2021, FSSAI amended the Food Product Standards and Food Additives Regulations to define dairy analogues, clarifying that they cannot be considered milk, milk products, or composite milk products. These analogues must also clearly disclose the ingredients used instead of milk.

Under the Food Safety and Standards (Advertising and Claims) Regulations, 2018, all claims made for smart protein products must be truthful, clear, and non-misleading. Specific rules apply to nutrition, health, and disease-risk-reduction claims. FSSAI and the Advertising Standards Council of India (ASCI) monitor compliance. GFI India has also prepared an Advertising and Claims Guide to support companies in this sector.The Ministry of Science and Technology has played a major role in advancing research on smart proteins in India.

1. **Department of Science and Technology (DST):** In 2021, SERB included cultivated meat research under its competitive grant programs.

2. **Department of Biotechnology (DBT):** Aims to position India among the world's top five biomanufacturing hubs by 2025, growing the sector to $150 billion. Its National Biotechnology Development Strategy emphasises food production and includes consultations with smart protein experts. In 2023, smart protein was identified as one of six priority sectors for high-performance biomanufacturing.

3. **Biotechnology Industry Research Assistance Council (BIRAC):** A key DBT initiative supporting biotech innovation through funding, technology transfer, IP management, and startup support. BIRAC has already funded several smart protein startups through programs like the Biotechnology Ignition Grant (BIG).

4. **Office of the Principal Scientific Advisor (PSA):** Advises national leadership on scientific priorities. In 2023, smart proteins were highlighted as an emerging technology during the PM-STIAC meeting, signalling strong policy interest.

Opportunities for India

India is at a unique intersection of dairy tradition and technological growth. Lab-grown milk offers several new possibilities:

1. **High-Value Dairy Protein Industry:** India imports significant quantities of whey protein for the sports nutrition market. According to recent market research, India is projected to import nearly 23,000 metric tonnes of whey protein in 2025, a 20% increase from 2024. Lab-grown milk proteins can reduce imports and position India as an exporter.

2. **Climate-Smart Dairy Innovation:** US start-up Perfect Day received GRAS status in 2020 for whey protein produced by *T. reesei*, reporting 85–97% lower greenhouse gas emissions than conventional milk protein, with most emissions from energy use (Perfect Day, 2021). Their calculations assign most of the environmental burden to by-products; therefore, allocating it entirely to protein would increase emissions. Precision fermentation could make alternative proteins cheaper and far more resource-efficient than animal proteins—using less land, feed, water, and time while producing far less waste (Tubb & Seba, 2021).

3. **Growth of Start-ups:** Several Indian start-ups, such as Zero Cow Factory and Phyx44, are already developing fermentation-derived casein and whey proteins to create animal-free dairy products. Some Indian biotech firms, such as Aamikza Biotechnology, focus on microbial cultures for traditional dairy fermentation (yoghurt, curd, cheese) rather than on full milk proteins. On the production side, Sterling Biotech, in collaboration with global partners, has begun building India's first precision-fermentation dairy protein facility in Gujarat to supply fermentation-derived proteins at scale. Indian dairy and veterinary research institutes can further support innovation by partnering with these start-ups on pilot studies, developing locally adapted microbial strains and cost-effective substrates, ensuring quality control and safety, and providing training in fermentation and bioprocessing. Such collaborations can help India emerge as a global hub for smart dairy, complement traditional milk production, and create new value-added opportunities for farmers and cooperatives.

4. **Employment in Biotech and Fermentation:** New skills are also expected to emerge in areas such as bioprocess engineering, fermentation science, downstream processing, and food formulation—strengthening and complementing India's rapidly expanding biotechnology ecosystem.

5. **Opportunities for Traditional Dairy Cooperatives:** Cooperatives such as AMUL, Nandini, and Mother Dairy are well-positioned to integrate precision-fermentation dairy into their product portfolios. By diversifying into high-protein beverages, lactose-free milk powders, specialty ingredients, and premium ice creams, these cooperatives can capture emerging market segments that value nutrition, convenience, and sustainability. Such products can be developed alongside traditional milk-based offerings, allowing cooperatives to expand their revenue base without disturbing the core dairy economy. Rather than replacing conventional dairying, these innovations

can strengthen the sector by creating new value-added opportunities for processors, retailers, and consumers.

Challenges and Concerns for India

Despite promising opportunities, several hurdles must be addressed.

1. **Regulatory Framework:** The Food Safety and Standards Authority of India (FSSAI) does not recognise lab-grown or precision-fermented milk as "milk," and therefore, such products cannot be marketed using dairy terminology. In this context, the regulatory framework will play a critical role in shaping consumer perception, confidence, and acceptance of these emerging alternatives.

2. **Concerns for Smallholder Farmers:** In rural India, small and landless farmers typically own just one to three milch animals, making dairying an essential source of daily income and nutritional security. The introduction of lab-grown milk has sparked concerns about price competition, reduced demand for cow's milk, and potential disruptions to rural livelihoods. However, most experts agree that precision-fermented dairy is more likely to complement—rather than replace—the traditional dairy sector, creating parallel markets that can coexist without undermining the rural economy. A recent analysis by Eisner (2024) points out that disruptions caused by precision fermentation in the livestock sector are not entirely new. In the past, certain animal-derived products—such as insulin and rennet—were rapidly replaced by microbially produced alternatives. Interestingly, this shift did not occur only because of cost savings or concerns about animal welfare. In many cases, the microbial versions simply performed better. For example, microbial rennet is now widely preferred in cheese production because it offers greater enzyme specificity, more consistent performance, and higher yields than traditional calf rennet. This historical precedent illustrates how precision-fermented products can gain dominance when they offer clear functional advantages, not just ethical or environmental ones.

3. **Technological Barriers:** Key technological hurdles also remain, including the high cost of fermentation equipment, reliance on imported microbial strains and enzymes, energy-intensive purification steps, and the growing need for skilled manpower to operate and maintain these systems.

4. **Consumer Perception:** Indian consumers prefer fresh, natural milk. Products grown "in a lab" may face skepticism. Consumer surveys show that while people are generally willing to try cell-based dairy products, they hesitate to regularly replace conventional dairy. This reluctance mainly stems from concerns about taste, naturalness and safety, higher expected prices, and strong cultural attachment to traditional dairy (George, 2023). Although several consumer studies have examined the acceptance of precision fermentation technology and animal-free dairy products (Banovic *et al*., 2024; Banovic & Grunert, 2023; Broad *et al*., 2022; Zollman Thomas & Bryant, 2021), none have investigated consumer preferences or willingness to pay for lab-grown milk in a cross-cultural context, nor compared it directly with conventional and plant-based milk. Existing research highlights a clear dichotomy: consumers increasingly recognise the potential of precision fermentation technology and animal-free proteins to address climate change and animal-welfare concerns, yet they remain cautious due to perceived health and safety

risks, particularly those associated with genetically modified organisms (Banovic & Grunert, 2023; Banovic & Grunert, 2024; Zollman & Bryant, 2021).

5. **Environmental Trade-offs:** While precision fermentation uses significantly less land, it can be energy-intensive, requiring high electricity, nutrient-rich feedstock, and careful wastewater management. The overall sustainability of the process largely depends on the energy source used. Microbially produced milk proteins have an environmental footprint similar to that of traditional dairy, with the largest contributions from sugar and electricity use (Behm *et al*., 2022). But there's room for improvement. Using renewable energy and greener carbon sources, along with advances in microbial technology, could make these lab-grown proteins much more climate-friendly. At the same time, conventional milk can also become more sustainable by reducing methane emissions from cows.

Environmental & Ethical Dimensions

1. **Environmental Benefits:** It offers notable environmental advantages, including a major reduction in enteric methane emissions (since no cattle are involved), around 90% lower land use, and less pressure on grazing areas and fodder crop cultivation, making it a more resource-efficient production model.

2. **Ethical Advantages:** It also appeals to ethically conscious consumers, as it avoids animal exploitation, eliminates the use of antibiotics or growth hormones, and supports the growth of cruelty-free dairy markets.

3. **Food Safety Benefits:** From a food safety perspective, precision-fermented dairy poses no risk of zoonotic pathogens and reduces the likelihood of adulteration, ensuring a safer, more consistent product for consumers.

Recommendations

1. **Expand affordable smart protein options:** Focus on cost-effective, scalable fermentation technologies to address India's protein deficiency.

2. **Strengthen public–private partnerships:** Promote collaboration among cooperatives, start-ups, and universities to advance accessible fermentation and biomanufacturing solutions.

3. **Support smallholder farmers:** Provide diversification schemes, value-addition programs, and training in bio-based enterprises to protect rural livelihoods.

4. **Invest in indigenous biotechnology:** Develop local microbial strains, low-cost substrates from agricultural waste, and scalable bioreactors to reduce reliance on imported technologies.

5. **Increase investment in core subsectors:** Prioritize funding for precision and biomass fermentation, alternative fats, cultivated seafood, cultivated dairy, and B2B ingredient technologies.

6. **Leverage India's biomanufacturing strengths:** Use existing biopharma and fermentation capabilities to integrate into global supply chains and attract international partnerships.

7. **Enhance technical assistance:** Offer support in fermentation development, protein extraction, commercialisation, and ESG monitoring to de-risk early ventures.

8. **Adopt innovative financing models:** Use blended finance to build essential infrastructure, pilot plants, and scale-up facilities.

9. **Boost public-sector support:** Strengthen government involvement in infrastructure, agri-integration, export linkages, and incubation to grow the smart protein ecosystem.

Future Outlook for the Indian Dairy Sector

India's dairy system does not need to choose between cows and fermenters—they can coexist in a hybrid model. Traditional dairy will continue to dominate, providing milk for drinking, sweets, ghee, and other culturally significant products, while lab-grown dairy can serve specialised segments such as sports nutrition, infant formula, medical foods, functional dairy proteins, and speciality cheeses. Collaboration between start-ups and cooperatives can further enhance the value of traditional dairy supply chains. At the same time, academic and government support will be critical: promoting fermentation research & development, training youth in biotechnology, developing cost-effective Indian microbial strains, and establishing clear FSSAI guidelines. By taking the lead early, India can secure a significant economic advantage in this emerging sector.

CONCLUSION

The smart protein sector in India has experienced significant growth over the past 3–5 years. What began as a small, emerging space has evolved into a dynamic ecosystem marked by research breakthroughs, startup growth, and increasing government engagement. Lab-grown milk is more than a technological breakthrough—it represents a shift towards sustainable, climate-resilient food systems. For India, it offers both opportunities and challenges. While it cannot replace traditional dairy (especially in rural India), it can complement the sector by creating new markets for high-value dairy proteins, reducing imports, supporting biotech entrepreneurship, and contributing to sustainability goals. The key lies in balanced integration: embracing innovation while protecting rural livelihoods and cultural dairy traditions. With proactive policies, R&D investment, and stakeholder collaboration, India can emerge as a global leader in both conventional and fermentation-derived dairy.

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