ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2025): 4.97
IJAFS 2025; 7(12): 207-212
www.agriculturaljournals.com
Received: 07-10-2025
Accepted: 08-11-2025

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Dragon fruit-enriched dairy products: Formulation, shelf-life, consumer perception and extension approaches for market integration

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DOI: https://www.doi.org/10.33545/2664844X.2025.v7.i12c.1043

Abstract
The inclusion of dragon fruit (*Hylocereus* spp.) in dairy formulations presents a valuable opportunity to create functional, nutritious, and visually attractive dairy products enriched with key bioactive compounds such as betalains, anthocyanins, and flavonoids. Beyond formulation and product stability, the successful commercialization of these innovations depends on comprehensive extension strategies that emphasize effective technology transfer, capacity building, and participatory engagement among farmers, processors, and consumers. Training initiatives, demonstration trials, and digital extension platforms play a crucial role in translating research into practice, enhancing stakeholder knowledge, and promoting consumer awareness of the health benefits and sensory qualities of dragon fruit enriched dairy products. Furthermore, entrepreneurship development and market linkage initiatives can empower dairy entrepreneurs to adopt these novel formulations, supporting sustainable market integration and improved livelihoods. This integrated extension framework is vital for accelerating adoption, enhancing product quality, and meeting the growing consumer demand for functional dairy foods. Therefore, merging biotechnological innovation with strong extension strategies can effectively drive the scaling and acceptance of dragon fruit enriched dairy products across diverse markets. This review highlights the nutritional, technological, and extension aspects of dragon fruit utilization in dairy, emphasizing its broad potential to transform the dairy sector through scientifically grounded and stakeholder-driven approaches.

Keywords: Dragon fruit, dairy products, antioxidants, shelf life, sensory properties

1. Introduction
Innovation in dairy products is essential for satisfying consumer expectations and stimulating market growth. The incorporation of fruits enhances nutritional value, sensory characteristics, and functional properties while supporting sustainability (Salehi, 2021; Voşgan *et al.*, 2016) [38, 47]. Studies show that Amazonian fruits improve both sensory quality and microbial development in dairy products (Oliveira *et al.*, 2024) [25], while persimmon increases carotenoid bioaccessibility in whole milk (García-Cayuela *et al.*, 2018) [53]. Fruit-enriched dairy products are rich in bioactive compounds that promote antioxidant activity and support gut health (Prestes *et al.*, 2021) [31]. This development reflects the growing consumer interest in foods that not only provide appealing flavors but also enhance overall health and well-being. Therefore, integrating fruits into dairy products offers a promising path for creating innovative functional foods that align with contemporary dietary trends and preferences.
Dragon fruit, known for its abundance of antioxidants and bioactive compounds, holds considerable promise for advancing dairy innovation. This review examines its nutritional advantages, processing considerations, and market potential.

2. Nutritional and Functional Properties of Dragon Fruit
2.1 Chemical composition of Dragon fruit
Dragon fruit is primarily cultivated in three main varieties: *Hylocereus undatus* (red skin, white flesh), *Hylocereus polyhizus* (red skin, red flesh), and *Hylocereus megalanthus* (yellow skin, white flesh) (Hunt, 2006; Hamidah *et al.*,2017) [14, 11]. It is a rich source of essential minerals such as potassium, phosphorus, sodium, and magnesium often exceeding the levels

found in fruits like mangosteen, mango, and pineapple (Gunasena *et al.*,2007; Stintzing *et al.*,2003) [10, 41]. The fruit provides glucose, fructose, dietary fiber, and vitamins, with its pulp comprising 82.5-83.0% moisture, 0.16-0.23% protein, 0.21-0.61% fat, and 0.7-0.9% fiber (TFIDRA, 2005; Rao & Sasanka, 2015) [45, 35]. The red-fleshed variety is especially rich in betalains, which act as natural colorants and potent antioxidants (Perween *et al.*,2018) [29]. Additionally, dragon fruit contains significant amounts of vitamins B1, B2, B3, and C, is high in fiber, and its seeds provide essential fatty acids (Sonawane, 2017; Ortiz-Hernandez & Carrillo-Salazar, 2012) [40, 26].

2.2 Bioactive Components in Dragon Fruit

Dragon fruit is abundant in antioxidants such as phenolic compounds, flavonoids, and anthocyanins, which are responsible for its numerous health-promoting properties. *Hylocereus polyrhizus* exhibits higher phenolic content and antioxidant activity compared to *Hylocereus undatus* (Chen *et al*., 2024; Arivalagan *et al*., 2021) [4, 1]. Anthocyanins, including cyanidin 3-glucoside, along with betacyanins, enhance the fruit's vibrant color and provide chemopreventive effects (Saenjum *et al*., 2021; Paśko *et al*., 2021) [36, 27]. The seeds also contain bioactive compounds such as epicatechin gallate and gallic acid, which possess anti-inflammatory properties (Nishikito *et al*., 2023) [24]. Moreover, dragon fruit serves as a source of phytosterols, fatty acids, and flavonoids (Hossain *et al*., 2021; Crane & Balerdi, 2005) [13, 7].

Fig 1: Varieties of Dragon Fruit with Distinct Skin and Flesh Colors

Table 1: Shows the chemical of different varieties of Dragon fruit

Components	*Hylocereus undatus*	*Hylocereus megalanthus*	*Hylocereus costaricensis*
Carbohydrate (g/100 g)	17.02±0.63a	15.76±1.05a	6.61±1.03a
Protein (g/100 g)	0.22±0.02b	0.35±0.04a	0.40±0.02a
Fat (g/100 g)	0.09±0.01a	0.06±0.01a	0.07±0.02a
Moisture (%)	82.00±0.58b	83.00±1.15b	91.33±0.88a
Crude fiber (g/100 g)	0.07±0.01b	0.13±0.02ab	0.32±0.07a
Ash (g/100 g)	0.60±0.06b	0.70±0.12b	1.27±0.09a
Energy (Kcal/100 g)	69.74±2.44a	64.97±4.25a	28.68±4.07b

2.3. Health Benefits of Dragon Fruit

Dragon fruit is a nutrient-dense fruit that offers numerous health benefits due to its rich bioactive compounds. It promotes gut health by supporting the growth of beneficial bacteria, exhibits strong antioxidant activity that helps lower the risk of chronic diseases, and contributes to cardiovascular well-being by helping regulate blood pressure (Wichienchot *et al.*,2010; Sonawane, 2017; Patel & Ishnava, 2019) [48, 40, 28]. Being high in vitamin C, iron, and magnesium, it enhances immunity and overall health (TFIDRA, 2005) [45]. Its anti-inflammatory and chemopreventive components help reduce inflammation and selectively inhibit cancer cell growth (Nishikito *et al.* 2023; Joshi & Prabhakar, 2020) [24, 16]. Furthermore, dragon fruit supports eye health, aids in weight management, and promotes digestive health by improving gut microbiota balance and stimulating short-chain fatty acid production (Chumroenvidhayakul, 2022; Chatterjee *et al.*,2024; Ho *et al.*,2024) [5]. These attributes make dragon fruit a valuable ingredient in the development of functional foods.

3. Applications in Dairy Products

Dragon fruit is increasingly utilized in dairy products for its capacity to enhance both sensory qualities and nutritional value. Its natural pigments, abundant antioxidants, and dietary fiber contribute to better texture, flavor, and overall consumer appeal. Several studies have optimized the incorporation of dragon fruit into dairy formulations, resulting in improved quality in products such as ice cream, yogurt, milk-based beverages, cheese spreads, and gelato.

Dragon Fruit in Ice Cream

Dragon fruit oligosaccharides function as prebiotic compounds that enhance the quality of ice cream. An optimal concentration of 4.00 g/100 g, when used with stabilizers (0.20-0.80 g/100 g) and sucrose (8.00-12.00 g/100 g), has been shown to significantly improve the sensory characteristics of ice cream, resulting in better texture, sweetness, and mouthfeel (Wichamanee *et al.*,2016) [56]. Moreover, the addition of 6% red dragon fruit peel to *kulfi*, a traditional frozen dairy dessert, improves its physical qualities particularly texture and color making it more attractive and nutritionally rich (Waladi *et al.*,2015) [57].

Another study proposed an optimal formulation for dragon fruit ice cream, recommending a blend of 80-100 parts dragon fruit, 100-120 parts yogurt, and 60-80 parts milk, along with natural sweeteners such as rock candy and honey. This formulation enhances both sensory properties and nutritional value by incorporating natural sugars and functional bioactive compounds from dragon fruit (Zhang & Lin, 2014) [52].

Dragon Fruit in Yogurt

The incorporation of dragon fruit puree into yogurt improves viscosity, acidity, and bioactive compound levels. Research has determined that 31.42 g of dragon fruit puree

is the optimal amount for enhancing yogurt's viscosity and acidity, leading to improved texture and probiotic activity (Yankey *et al.*,2023) [49]. In addition, fortifying yogurt with 20% red dragon fruit peel extract increases viscosity and total acidity while lowering pH and syneresis (whey separation), resulting in a more stable and desirable product consistency (Pradana *et al.*,2023) [30].

To maximize nutritional benefits, adding 20% dragon fruit juice to yogurt increases its vitamin C content and antioxidant capacity, making it a functional food with potential health-promoting effects (Afwan *et al*). However, for optimal sensory appeal, a lower concentration of 10% dragon fruit juice is preferred, as it offers the best balance of flavor, texture, and consumer satisfaction (Produksi *et al.*,2023) [32].

Dragon Fruit in Milk Beverages

Dragon fruit is also used in the preparation of flavored milk beverages, where it imparts natural color and enhances nutritional value. Research indicates that blending 15-20 parts of dragon fruit juice with 10 parts of milk yields a well-balanced drink with a pleasant flavor and rich nutritional profile (Yinsheng & Zhenlong, 2012) [50]. Its natural sweetness and abundance of bioactive compounds make dragon fruit an excellent ingredient for developing milk-based functional beverages.

Dragon Fruit in Cheese Spreads

Cheese spreads enriched with dragon fruit have attracted interest due to their improved flavor, texture, and health-promoting properties. Using 40% red dragon fruit has been shown to achieve optimal sensory qualities, enhancing both the taste and spreadability of the cheese while preserving a creamy, desirable texture (Umar *et al.*,2019) [46]. Additionally, the natural pigments in dragon fruit provide an appealing color, further boosting consumer attractiveness.

Dragon Fruit in Gelato

Another innovative use of dragon fruit in dairy is in dadiah gelato, a fermented frozen dessert. Studies have demonstrated that adding 35% red dragon fruit skin markedly improves the color, aroma, and flavor of dadiah gelato, resulting in a visually attractive and nutritionally enriched product (Yunianti *et al.*,2024) [51]. The fruit's high fiber content also enhances the dessert's health benefits.

4. Impact on Different properties: Incorporating dragon fruit into dairy products improves their nutritional profile by enhancing antioxidant activity and potential immunomodulatory effects (Sulistyarini *et al.*, 2024) [42]. It also contributes to better flavor, color, and overall nutrient content in products such as yogurt, ice cream, and soft candies (Tarte *et al.*,2023; Yunianti *et al.*,2024) [44, 51]. The addition of red dragon fruit to goat milk-based soft candy notably increases organic matter, protein, and fat content, particularly at higher levels (40-45%) (Sulistyowati *et al.*,2023) [43]. While red dragon fruit peel can boost protein content, its effect on iron fortification using Fe NaFeEDTA is limited, indicating the need for complementary fortification approaches (Gunawan *et al.*,2021) [55].

5. Functional Properties

Dragon fruit improves the antioxidant activity, sensory qualities, and storage stability of dairy products. It enhances radical scavenging activity and total phenolic content, helping to reduce oxidative stress and support immune function. Its natural pigments contribute to better color, texture, and emulsification in products like ice cream and soft candy (Rahayu *et al.*,2024) [34]. Being rich in vitamins and bioactive compounds, dragon fruit fortifies dairy products, enhancing their functional properties and immunomodulatory effects. Sensory evaluations indicate improved taste and texture in gelato, yogurt, and ice cream, with 10-15% dragon fruit juice providing optimal consumer acceptance (Putri *et al.*,2019; Siregar *et al.*,2023) [33, 39]. Furthermore, its antioxidant and antibacterial properties help extend shelf life, with fermented dragon fruit juice maintaining freshness for up to three months and stabilizing yogurt by reducing betacyanin degradation and syneresis (Muhialdin *et al.*,2020; Gengatharan *et al.*,2017) [20, 54].

6. Potential Challenges and Limitations

The highly perishable nature of dragon fruit requires careful formulation to maintain the year-round availability and stability of dairy products (Sahrwat *et al.*,2023) [37]. While incorporating dragon fruit may enhance the shelf life of dairy products due to its antioxidant properties, research specifically addressing this effect remains limited (Tarte *et al.*,2023) [44].

7. Future Trends and Perspectives

The future of dragon fruit in dairy products presents promising opportunities for innovation and sustainability. Its combination of bioactive compounds including antioxidants, vitamins, and probiotics enhances anti-inflammatory, antioxidant, and gut-health benefits (Patel & Ishnava, 2019; Wichienchot *et al.*, 2010) [28, 48]. Smart packaging leveraging dragon fruit's betacyanins could extend shelf life and reduce the need for preservatives (Paśko *et al.*, 2021) [27]. Personalized nutrition may drive the creation of dragon fruit-enriched dairy products tailored to specific health requirements (Chumroenvidhayakul, 2022) [5]. Its incorporation into plant-based dairy alternatives provides antioxidant-rich, creamy options (Ho *et al.*, 2024) [12]. Zero-waste approaches could utilize both the flesh and peel for fiber and prebiotics, minimizing food waste (Yunianti *et al.*, 2024) [51]. In fermented dairy products such as kefir and lassi, dragon fruit supports probiotic-rich functional benefits. AI-driven optimization could further refine formulations to align with consumer preferences (Joshi & Prabhakar, 2020) [16]. Additionally, its natural gelling properties offer a clean-label alternative to artificial thickeners in yogurts and puddings (Liaotrakoon, 2013) [18]. These developments underscore dragon fruit's potential to drive both innovation and sustainability in the dairy industry.

8. Extension Strategies for Dragon Fruit Enriched Dairy Products: Three Key Perspectives

8.1 Technology Transfer and Knowledge Dissemination

Technology transfer constitutes a fundamental pillar for bridging the gap between research innovations and practical applications in dairy product development. The successful commercialization of dragon fruit enriched dairy formulations requires systematic technology transfer mechanisms that connect research institutions with dairy processors, entrepreneurs, and farmers (Neethirajan, 2023) [23]. Modern approaches emphasize the integration of digital

technologies including artificial intelligence and machine learning to enhance the efficiency of dairy processing systems, enabling real-time optimization of production processes and quality control (Freire *et al.*,2024) [9]. Furthermore, capacity building through structured training programs plays a critical role in equipping stakeholders with technical knowledge on value-added product development, processing techniques, and quality management systems. Recent initiatives demonstrate that collaborative multi stakeholder outreach and direct industry connections significantly accelerate the adoption of dairy innovations and support workforce pipeline development (NDFRC, 2023) [22]. The establishment of technology transfer units at research centers, coupled with pilot demonstrations at dairy cooperatives, facilitates the dissemination of novel formulation technologies while addressing practical implementation challenges faced by processors.

8.2 Participatory Approaches and Consumer Education

Participatory research methodologies have emerged as transformative strategies for developing consumer centric dairy innovations that align with market expectations and societal values. Including diverse stakeholders' citizens, farmers, processors, and researchers in co design processes enables the exploration of innovative solutions that break from conventional fixations, with citizens particularly contributing original concepts due to their limited bias toward existing production systems (Coeugnet *et al.*,2023) [6]. Digital extension services leveraging Information and Communication Technology (ICT) tools have demonstrated substantial impact on dairy production and household welfare, with studies showing that ICT-based extension can increase milk production by 13%, milk income by 29%, and household income by 22% (Marwa *et al.*,2024) [19]. Consumer education remains equally critical, as targeted nutrition education campaigns highlighting health benefits of functional dairy products have been shown to increase dairy product consumption by 20-26%, emphasizing the importance of educational cues at multiple touchpoints (Dairy Nutrition Education Study, 2024) [8]. The integration of participatory rural appraisal techniques and farmer field demonstrations further strengthens adoption rates by addressing practical constraints and building confidence among stakeholders through hands on experience with dragon fruit dairy product manufacturing processes.

8.3 Entrepreneurship Development and Market Integration

Entrepreneurship development schemes and market linkage strategies are essential for translating technological innovations into viable commercial enterprises within the dairy sector. Government initiatives such as the Dairy Entrepreneurship Development Scheme (DEDS) have historically provided financial assistance ranging from 25% to 33.33% capital subsidy for establishing dairy processing units, value addition facilities, and marketing infrastructure, thereby stimulating self-employment and rural enterprise development (NABARD, 2023) [21]. The emergence of digital dairy management systems and blockchain-enabled supply chains offers unprecedented opportunities for ensuring traceability, quality assurance, and market transparency in functional dairy products, addressing critical consumer concerns about food safety and authenticity (Kumar & Kumar, 2023) [17]. Market linkage programs connecting dairy farmers with processors and retailers have demonstrated measurable economic benefits, with improved farm-to-market connections increasing dairy revenues by over $1,000 per farmer through reduced intermediation and better price realization (ILRI, 2022) [15]. Training programs focusing on entrepreneurship skills, business planning, packaging innovations, and digital marketing strategies empower dairy entrepreneurs to successfully commercialize novel products like dragon fruit-enriched formulations. The integration of sensory evaluation training, quality certification support, and access to testing facilities further strengthens the entrepreneurial ecosystem, enabling small-scale processors to compete effectively in premium functional dairy product markets while ensuring consistent quality standards and consumer acceptance.

9. Future Prospects

The future of dragon fruit-enriched dairy products offers promising opportunities for innovation and sustainability. Future research should focus on optimizing processing and storage techniques, such as microencapsulation and high-pressure processing, to preserve bioactive compounds and enhance shelf-life. Integration of artificial intelligence for formulation optimization could tailor products to consumer preferences and improve quality control. Expanding use in plant-based and hybrid dairy alternatives can meet the growing demand for lactose-free and vegan options, while utilizing dragon fruit by-products supports zero-waste and circular economy principles. The development of smart packaging using natural pigments from dragon fruit can improve product safety and reduce preservatives. Additionally, dragon fruit's natural gelling properties hold potential as clean-label alternatives to synthetic stabilizers in dairy items. Strengthening technology transfer, entrepreneurship development, and digital traceability will be vital for commercialization and consumer trust. Clinical validation of the synergistic health benefits of dragon fruit bioactives and dairy nutrients can further position these products in the nutraceutical market. Collectively, these advancements underscore dragon fruit's potential to drive functional dairy innovation aligned with modern health, sustainability, and market trends.

10. Conclusion

Incorporating dragon fruit into dairy products enhances their nutritional, functional, and sensory properties. Rich in antioxidants, vitamins, and bioactive compounds like betacyanins, it boosts health benefits, improves texture, and adds vibrant color and flavor, making it ideal for yogurt, ice cream, and beverages. However, challenges such as perishability, seasonality, and physicochemical changes impact product stability and consumer acceptance. Future research on processing, storage, and formulation can address these issues while exploring its use as a natural colorant, emulsifier, and ingredient in plant-based dairy. With sustainability efforts utilizing fruit by-products, dragon fruit holds great potential in the dairy industry. Extension efforts focusing on capacity building, digital outreach, and multi-stakeholder engagement play a crucial role in translating scientific advancements in dragon fruit-dairy formulations into practical, market-ready products. This integrated extension framework promises to drive wider adoption, improve livelihoods, and contribute to the growing demand for functional dairy products in diverse markets.

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