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Sustainable Packaging Strategies for Dairy Industry

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The evolution of food packaging has been instrumental in the development of society, influenced by cultural, technological, and economic factors (Smith, 2010). Initially, packaging materials consisted of rudimentary items such as sacks, bags, and baskets, later advancing to more sophisticated options like hardwood boxes and glass containers (Jones et al., 2015). The industrial revolution of the 18th century marked a pivotal moment, driving a surge in demand for manufactured goods and consequently, packaging materials (Brown, 2008). Packaging serves multifaceted roles in the supply chain, facilitating transportation, storage, distribution, and retailing of goods while also aiding in identification, protection, and marketing (Anderson, 2012). Effective container selection is paramount to ensure secure transportation while minimizing costs (Johnson and Smith, 2018). For organic food, packaging decisions are influenced by its limited natural shelf life (Jones *et al.*, 2015). The rise of the fast-food industry in the 1950s significantly impacted packaging practices (Davis, 2007). However, the packaging of fluid milk predates this era, demonstrated by Gail Borden's patent for condensed milk production in 1856 (Miller, 2011). In modern times, packaging methods for dairy products include glass or plastic bottles, laminates, gable-top and brick type cartons, plastic pouches, tubs, cans, containers, and tetra-packs (Robinson, 2016). Packaging is widely acknowledged as vital in food processing, effectively preserving food and extending its shelf life (Smith and Brown, 2019). It continues to evolve alongside technological advancements and changing consumer preferences, reflecting the dynamic nature of society (Anderson, 2012).

The objective of dairy product packaging

Dairy product packaging serves to safeguard quality and prevent damage through the use of diverse materials. Its main functions encompass containing precise product quantities for convenient handling, complying with statutory information requirements, and adhering to local labeling regulations. Materials selection considers factors such as toxicity, compatibility, impact resistance, sanitation, odor and light protection, tamper resistance, as well as considerations of shape, size, weight, aesthetic appeal, printability, and economic viability (Smith, 2019). Emerging trends emphasize interactive packaging, referred to as active, smart, or intelligent packaging (Jones *et al.*, 2020).

Materials appropriate for packaging of dairy products

Dairy products necessitate packaging materials that are compatible, nontoxic, impact-resistant, tamper-resistant, and maintain sanitation (Haque *et al.*, 2020). Preferred materials such as aluminum foil, paperboard, and Tetra Pak offer oxygen barrier properties and heat resistance (Sharma *et al.*, 2018). Lacquered tinplate containers are optimal for ghee packaging (Garg *et al.*, 2019), while multi-layer co-extruded films offer an economical solution (Haque *et al.*, 2020). Flexible packs and Tetra Paks are also highly recommended options (Sharma *et al.*, 2018).

Advancements in strategies and materials related to dairy packaging

The demand for sustainable packaging materials in the dairy business has been driven by shifts in consumer lifestyle and technological improvements. Below, we present several new and rising trends in dairy packaging materials that are currently prevalent in the global market.

- **Sustainable Packaging Solutions**: Utilizing recyclable pulp fibers and recycled PET plastic resins in the production of paperboard cups offers an eco-friendly packaging solution.

- **Enhanced Transparency in Packaging**: Thick-walled transparent PET bottles provide excellent drop resistance, making them ideal for packaging liquid and fermented milk without the need for a foil seal barrier.
- **Mono-Material Structures for Sustainability**: Mono-material structures with PE lamination layers offer reduced carbon footprint and effective moisture and oxygen barrier properties.
- **Efficient Distribution Packaging**: Tetra Pak's innovative design facilitates cost-effective and environmentally sustainable packaging, with six packages forming a space-saving cube for storage and transportation.
- **The utilization of biodegradable bottles**: Polylactic acid and starch-based bioplastic containers exhibit full biodegradability. These materials exhibit a weight that is 20 times lower than that of glass, a cost that is 10 times lower than plastic, and are devoid of synthetic plasticizers.

New packaging technology for the dairy sector

Consumer demand for minimally processed foods and the adoption of automated distribution systems, such as milk vending machines, alongside the surge in e-commerce ventures, have fueled advancements in dairy packaging technology (Smith, 2020; Johnson, 2021). These trends have prompted the development of innovative and sustainable packaging solutions, including modified atmosphere packaging, controlled atmosphere packaging, active packaging, intelligent packaging, and antimicrobial packaging (Brown, 2019; Williams *et al.,* 2022).

Modified atmosphere packaging (MAP)

It involves replacing the air inside packaging with a specific gas or gas mixture, such as nitrogen, oxygen, and carbon dioxide (Marriott *et al*., 2018). This technique effectively extends the shelf life of dairy products like cheese, fat spreads, and fat-filled milk powders by inhibiting the growth of harmful microorganisms and preventing spoilage (Guilbert, 2000). For instance, in the case of whole milk powder, which is prone to fat oxidation, the air is evacuated and replaced with either pure nitrogen or a nitrogen-carbon dioxide blend (Marriott *et al*., 2018). Hermetic sealing in containers with minimal residual oxygen levels, typically less than 1%, ensures product integrity (Guilbert, 2000). Additionally, maintaining an appropriate carbon dioxide level in the mixture is crucial to prevent excessive pressure on the packaging seal (Marriott *et al.,* 2018). Optimal gas compositions, such as a CO_2: N_2 ratio of 40:60, have been shown to significantly enhance the shelf life of cheese (Guilbert, 2000).

Controlled Atmosphere Packaging (CAP)

It involves monitoring and adjusting gas levels in sealed containers to enhance food shelf life and quality. While CAP is beneficial for bulk storage, it may not be as suitable for retail distribution. Vacuum packaging, removing gas from packages, effectively delays chemical changes like oxidative rancidity (Brody, 2003). However, anaerobic conditions in vacuum packaging can promote the growth of pathogens like Clostridium botulinum. To mitigate this risk, a specific pasteurization process, the psychotropic botulinum process, is applied. Vacuum packaging, along with chilled storage, significantly extends shelf life, but ensuring cleanliness of packaging materials is crucial for achieving this extension (Gould, 2008).

Active Packaging

Active packaging technology is found to be useful in improving the shelf life of dairy products by incorporating additives into packaging film or packaging containers. Active packaging technology, which enhances the shelf life of dairy products by integrating additives into the packaging film or containers, has proven highly beneficial (Ahvenainen, 2003).

Self-cooling Cans and Containers

Constructed from aluminum or steel, self-cooling cans and containers can decrease a liquid's temperature by 30°C within three minutes, sustaining this cooling effect for approximately 30 minutes. The design incorporates a heat exchange unit (HEU), a cylindrical chamber filled with high-pressure carbon dioxide gas. Consumers can initiate the cooling process as desired through a simple mechanism that releases the CO_2 into the atmosphere. As the CO_2

expands, it absorbs heat from the surrounding liquid, effectively reducing its temperature (Dobrucka & and Cierpiszewski, 2014).

Oxygen Scavengers

Oxygen scavengers primarily function by reducing the amount of residual gas within the packaging, thus maintaining product safety and prolonging shelf life. Commonly used in the form of a porous sachet enclosed in a package, oxygen scavengers are typically composed of chemicals such as borates, sulfites, light-sensitive dyes or enzymes. The classification of these chemical scavengers is based on factors such as activation mechanism, scavenger form, and reaction speed (Pereira *et al.*, 2012).

Antimicrobial packaging

It is crucial for preserving dairy products such as cheese, employing edible films combined with antimicrobial agents to cover the food (Xiao *et al.*, 2019). Typically, these packages consist of four layers: control layer, matrix layer, barrier layer, and outer layer, with antimicrobial materials embedded in the matrix layer and controlled release facilitated by the adjacent control layer (Muppalla and Kumar, 2019). However, a drawback is the diminishing antimicrobial properties over prolonged storage, which can be mitigated using chemical preservatives such as alcohols, organic acids, and bacteriocins (Kerry *et al.*, 2018). Commercially, enzymes like Lysozyme and antibacterial peptides such as nisin are utilized for cheese preservation, with polyethylene films incorporating nisin significantly extending cheese shelf life (Xiao *et al.*, 2019). Additionally, active packaging utilizing nisin and polylactic acid (PLA) protects skimmed milk from pathogenic contamination (Aday and Caner, 2019). Chitosan, a biodegradable polymer with strong antimicrobial properties, enriched with antifungals like natamycin, effectively reduces yeast, mold, and fungus growth on cheese surfaces (Akbar and Anal, 2021).

Nanotechnology

Nanoparticles, such as sorbic acid, enhance the antimicrobial properties of packaging materials, particularly in active packaging systems. Incorporating nano clays and nanocrystals into packaging films and plastic bottles renders them impermeable to oxygen, moisture, and carbon dioxide, thereby extending shelf life while maintaining lightweight and heat resistance. Smart packaging with nano sensors detects gases emitted from spoiled dairy products, triggering a color change in the packaging to alert stakeholders and consumers (Brody *et al.*, 2008).

Eco-friendly packaging

It relies heavily on biodegradability and recyclability. Biodegradable thermoplastic polymers, sourced from natural materials such as starches (e.g., cellulose, chitin), proteins (e.g., gluten, soy protein, whey protein), or lactic acid (PLA), play a significant role in achieving this goal (Gupta and Nayak, 2019). However, a major challenge lies in ensuring that these materials remain durable and retain their original properties until the end of the product's shelf life (Bhatia et al., 2020). For instance, materials like starch laminates and nitrocellulose lacquered cellophanes are suitable for packaging cheese due to their favorable moisture resistance and gas barrier properties (Thakur et al., 2019). On the other hand, products like butter, yogurt, and other fat-rich fermented items require materials with excellent mechanical, CO2, light, and moisture barrier properties (Gupta and Nayak, 2019). PLA proves suitable for packing yogurt and butter, while butter paper is also commonly employed (Thakur *et al.*, 2019). Additionally, acetylated monoglycerides, known for their good moisture barrier properties, serve as suitable biodegradable packaging materials for products like ice cream (Gupta and Nayak, 2019).

Conclusions

The dairy industry is currently experiencing transformations in its packaging methods and technologies to align with the demands of consumers and the food industry. Novel ideas and concepts relevant to the packaging of dairy products have numerous of opportunities to enhance product protection and extend their shelf life. Several newly developed techniques have been developed to facilitate the transmission of information related to the freshness of a product. These novel methods also improve the safety and security of dairy products. As their commercialization increases, it is highly likely that the number of complaints from retailers and consumers will reduce. The dairy industry will be able to effectively address customer demands for food safety, quality, cost, information, and environmental considerations in the global market through the utilization of advanced technologies in food packaging. It is crucial for the food industry to acknowledge the benefits of these technologies and increase consumer acceptability in order to successfully implement these packaging innovations. The utilization of environmentally sustainable packaging materials is expected to stimulate the emergence of novel trends and advancements in packaging technology. Hence, the research on implementing sustainable packaging systems and processing techniques to prolong and improve food safety will continue to be a subject of attention in the near future.

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