



Endüstriyel Süt Ürünleri Enzimlerinde Güncel Yaklaşımlar

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Öz

Süt endüstrisinde enzimler, genellikle istenen özellikleri ve uzun raf ömrüne sahip yüksek kaliteli süt ürünleri elde etmek için kullanılmaktadır. Bu talep, enzimlerin sadece hayvansal kaynaklardan değil, aynı zamanda bitkisel ve mikrobiyal kaynaklardan da üretilmesine yol açmıştır. Süreç içerisinde süt ürünlerinde kullanılan enzimlerin üretimi, ticari açıdan önemli bir pay kazanmıştır. DNA teknolojisindeki ilerlemeler, mikroorganizmaların istenen enzimleri en aktif formlarında elde etmek için fabrika gibi kullanılmasına olanak tanımakla birlikte bu enzimler, ürünlerin kalitesini artırmak, üretim süreçlerini optimize etmek ve tüketicilere çeşitli seçenekler sunmak için kritik bir rol oynamaktadır. Ayrıca, enzim teknolojisinin süt endüstrisindeki uygulama alanlarını genişletmek ve sürekli olarak yenilikçi çözümler aramak, sektörde sürdürülebilirlik ve rekabetçilik açısından önem teşkil etmektedir. Gelecekteki çalışmalar ve araştırmalar, daha etkin ve çevre dostu enzimlerin geliştirilmesine odaklanmalıdır. Bu derlemede, süt endüstrisinde enzim kullanımının amaçları, yeni teknolojiler ve araştırma geliştirme konuları ele alınmıştır.

Anahtar kelimeler: Süt, süt ürünleri, endüstri, enzim, yeni teknolojiler

Current Approaches in Industrial Dairy Enzymes

Abstract

Enzymes are commonly used in the dairy industry to obtain high-quality milk products with desired characteristics and extended shelf life. This demand has led to the production of enzymes not only from animal sources but also from plant and microbial sources. The production of enzymes used in dairy products has gained significant commercial importance over time. Advances in DNA technology allow microorganisms to be used like factories to obtain required enzymes in their most active forms, playing a critical role in improving product quality, optimizing production processes, and offering consumers various options. Moreover, expanding the application areas of enzyme technology in the dairy industry and continually seeking innovative solutions are crucial for sustainability and competitiveness in the sector. Future studies and research should focus on developing more efficient and environmentally friendly enzymes. This review discusses the purposes of enzyme use in the dairy industry, new technologies, and research and development topics.

Key words: Milk, dairy, industry, enzyme, new technologies

Introduction

The increase in world population, climate change, migrations, and the resulting fluctuations in the economy have brought to light the need for a more detailed consideration of the food sector worldwide. The dairy sector has also been affected by these factors. Production must take place considering issues such as greenhouse gases, carbon footprint, and green energy. Countries must fulfill their commitments made under the Paris climate agreement. This can only be achieved by minimizing energy consumption, considering all sectors. Therefore, it is essential for all sectors to determine the most efficient and economical production techniques to carry out their productions (Singh et al., 2019).

The dairy industry is a significant part of the food industry, playing a crucial role in the daily nutrition of people worldwide. With advancements in processing milk and transforming it into various products, the importance of enzymes in the dairy industry has steadily increased (Fallahi et al., 2018). Enzymes serve as biological catalysts, accelerating chemical reactions, and are particularly useful in various applications within the food industry. Their utilization in the dairy industry is paramount, especially in processes such as cheese production, yogurt making, milk homogenization, and protein hydrolysis. Protease enzymes used in cheese production break down the milk protein casein, determining the texture, flavor, and consistency of cheese. Lipase enzymes contribute to cheese ripening by breaking down fats, leading to the development of unique flavors in cheese. In yogurt making, enzymes like lactase, used alongside lactic acid bacteria, hydrolyze lactose in milk, contributing to the acidity and texture of yogurt. Additionally, lipase enzymes employed in milk homogenization regulate the size of fat globules, ensuring a higher quality and stable structure of milk. (Khan ve Selamoglu, 2020; Kocabas et al., 2022).

The history of industrial milk production dates back approximately a century. Over this period, numerous studies have been conducted on the production steps of manufactured products, aiming to determine the most effective methods and components. Enzymes play a significant role in this industry. These enzymes can be of animal (Khan and Selamoglu, 2020) plant, or microbial (Kocabas et al., 2022) origin. However, due to the ease and cost-effectiveness of producing microbial enzymes, most enzymes used in the sector are microbial in origin. With advances in genetic engineering, enzymes with higher activity and efficiency are produced from recombinant microorganisms, sold commercially, and preferred most in the sector. Continued utilization of opportunities provided by science and technology will be essential for achieving sustainable sectoral development.

Enzymes are proteins that catalyze specific reactions. Enzymes are commonly used in the dairy industry to extend shelf life, improve taste and aroma, aid in cheese production, and ripen cheeses. Among the most used enzymes in the dairy industry are peptidase, catalase, lactase, proteinase, transglutaminase, lysozyme, and lipase. In addition to these enzymes, different types of enzymes that positively affect the texture of dairy products are also used (Srivastava, 2019). For example, Acetyl-coA synthase is a metabolic enzyme used to obtain volatile esters and sulphur compounds. There are numerous enzyme varieties commercially available and used in cheese production to enhance flavour through the emergence of different aromatic compounds. Most enzymes used in the dairy industry (proteases, rennet, chymosin, lipases, and lactases) belong to the hydrolase family. One of the most well-known and historically used enzymes in the dairy industry is rennet enzyme. Also known as rennin, it is a mixture of pepsin and chymosin enzymes that coagulate milk in cheese production. Initially obtained from animal sources, the growth of the dairy sector globally led to an insufficient supply, prompting a shift towards alternative enzyme production sources, with microbial sources being the most economical (Kittibunchakul et al., 2019).

Enzymes are also utilized to expedite the aging of cheeses. Enzyme-modified cheese technology is used for this purpose. Numerous new technologies are being researched and developed in today's studies. Cold-active enzyme technology is one such example, aiming to obtain enzymes that exhibit high activity at low temperatures. While not widely applied in the dairy industry, it is preferred in some processes. For instance, beta-galactosidase enzyme isolated from bacteria in Antarctica has been used in probiotic baby formulas (Chen et al., 2022). Quality product production is one of the most crucial elements in economic competition. The use of enzymes is vital in the production of dairy products such as yogurt, milk, and various cheese types. Efforts to achieve the best quality in dairy products also highlight the use of enzymes.

This review will delve into the types, functions, and industrial applications of enzymes used in the dairy industry. It will explore in detail the impact of enzymes on milk and dairy products, highlighting their crucial role in enhancing efficiency and product quality in industrial processes.

Enzymes Commonly Used in the Dairy Industry and Their Applications

Rennet

The rennet enzyme is a mixture of pepsin and chymosin enzymes. The use of this enzyme is crucial as it coagulates milk proteins, thus forming the basis of cheese production. Rennet is obtained from the fourth part of the stomachs of ruminant animals. It has been used by humans for approximately 6000 years. Although initially derived from animal sources, the demand for rennet from animal sources cannot be met sufficiently today, leading to the use of microbial sources. Production has been ongoing in this manner for many years, and the best commercial rennet varieties are produced using genetic modification techniques to optimize their activity (Abada, 2014). One important consideration in choosing the milk clotting enzyme to be used is the source of the milk, whether it is obtained from animals such as cows, goats, or sheep, which affects this selection.

Rennet enzyme is a key enzyme in the dairy industry and plays a crucial role in cheese production. This enzyme coagulates the casein proteins found in milk, thus initiating the curdling process. The areas of application and effects of rennet are as follows:

Cheese varieties and textures: Rennet enzyme is used in cheese making to create a wide range of cheese varieties and textures. By using this enzyme, soft cheeses (such as Mozzarella), semi-hard cheeses (like Cheddar), and hard cheeses (such as Parmesan) can be produced. Additionally, the use of rennet determines the texture of cheese, contributing to characteristics like softness, firmness, or the presence of holes in certain cheeses.

Cheese ripening and flavour development: The coagulation effect of rennet in milk initiates the cheese ripening process. During this process, enzymatic and microbial interactions inside the cheese lead to the development of its characteristic flavours and aromas. Therefore, the use of rennet is a significant factor in determining the flavour profile of cheese.

Beyond dairy industry use: Rennet enzyme is not only used in cheese making but also in the production of other dairy products. Particularly in the production of certain cheese-based desserts and yogurts, this enzyme plays a role in determining the consistency, texture, and flavour of these products.

Alternative enzyme sources and sustainability: Traditionally, rennet has been sourced mainly from animal origins. However, today there is a trend toward using alternative enzymes produced from microorganisms and genetic engineering methods. This shift is an important step in terms of sustainability and reducing environmental impact.

In conclusion, rennet is an essential component in cheese production within the dairy industry, influencing the diversity, texture, flavour, and ripening process of cheese. Proper utilization of this enzyme and exploration of alternative enzyme sources contribute to enhancing product diversity in the dairy industry while also addressing sustainability concerns.

Researchers in China have studied the milk clotting enzyme YS 1 obtained from a bacterial species called *Bacillus subtilis* YB-3 isolated from the Tibet region. Particularly, they have found that this enzyme is highly effective on Yak milk casein used in this region (Li et al., 2012).

Among the microbial sources commonly used in rennet enzyme production are *Aspergillus oryzae*, *Rhizomucor pusillus*, *Endothia parasitica*, and *Irpex lactis*. It is noted that the most effective result is achieved by using *Rhizomucor pusillus* for production in semi-solid media (Abada, 2019).

Lipase

The lipase enzyme is water-soluble, while its substrate, lipids, is insoluble. They catalyze the hydrolysis of ester bonds in lipids. Lipase enzyme is particularly used in dairy products to achieve and enhance desired flavours. It facilitates the modification of milk fat, thereby providing significant benefits when dairy products are used in different food items (Abada, 2019).

There are numerous microbial sources to produce lipase enzyme, making it economically feasible to produce and use. While not as prevalent as rennet enzyme, it is widely used in the dairy

industry. Studies have shown that lipases derived from fungi are produced more economically compared to those from bacterial sources. The LIPABASE program helps select the most suitable lipase enzymes based on its source for production. Lipases are crucial enzymes widely used in the dairy industry with various applications:

Cheese production: Lipase enzymes play a significant role in cheese production. Particularly used in various cheese types, lipases hydrolyze fats to enhance the aroma and flavour of cheese. For instance, lipases used in Italian Parmesan contribute to its distinctive sharp flavour and taste.

Yogurt and fermented products: Lipase enzyme finds application in certain yogurt and fermented dairy products as well. In these products, lipase hydrolyzes fats to create specific taste and texture. Moreover, lipases are known to be used in the production of some fermented cheeses.

Fatty dairy products: Lipases are crucial in the production of fatty dairy products. Especially in fatty cheeses and products like cream, lipase enzymes hydrolyze fats to improve the taste, texture, and consistency of products.

Kashar cheese production: Lipase enzyme holds critical importance in Kashar cheese production. Lipases facilitate the breakdown of fats and contribute to the distinctive flavor of Kashar cheese. Additionally, during the maturation process of Kashar cheese, lipases assist in developing its unique taste and texture.

Enhancing quality and taste: Lipases are generally used in the dairy industry to improve product quality and enhance taste profiles. The release of free fatty acids through fat hydrolysis enhances specific taste and aroma characteristics in products.

These details demonstrate the various application areas and significance of lipase enzyme in the dairy industry. Lipases are considered valuable tools to enhance the taste, aroma, and texture of dairy products and are indispensable components in the production of many different cheese varieties.

Among microbial lipase sources are *Serratia marcescens*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* (Abada, 2019).

Lactase (Beta-galactosidase)

Lactase enzyme, also known as beta-galactosidase, is an enzyme responsible for breaking down lactose. Lactose is a disaccharide naturally found in milk, and it is broken down in the intestinal tract into glucose and galactose. Lactase plays a key role in this process (Mobayed et al., 2021).

Production of lactase enzyme: Lactase enzyme is typically produced from biological sources such as microorganisms or yeasts. These sources are used on an industrial scale to produce lactase. Additionally, genetic engineering techniques can be employed for lactase production.

Application of lactase: In the dairy industry, lactase enzyme is primarily used to produce low-lactose or lactose-free milk and dairy products, especially for individuals with lactose intolerance. These products are tailored to be suitable for consumption by individuals who lack lactase enzyme production in their digestive systems. Furthermore, products made with lactase are often easier to digest and can be a preferred option for those with digestive issues.

Effects and benefits of lactase: The addition of lactase enzyme in dairy products aids in easier digestion for individuals with lactose intolerance, preventing digestive discomfort. This allows such individuals to benefit from the nutritional content of dairy products. Moreover, the consumption of lactase-treated products may contribute to overall digestive health.

Product variety: Lactase-treated products can encompass a wide range of offerings, including lactose-free milk, lactose-free yogurt, and lactose-free cheese. Diversifying these products to meet consumer demands underscores the importance of lactase in the dairy industry.

Product quality and marketing: Lactase-treated products often have an extended shelf life, enhancing their commercial value. Additionally, these products cater to health-conscious consumers and those with specific dietary needs, making them an attractive option and influencing marketing strategies.

In conclusion, lactase enzyme is a pivotal component in the dairy industry, facilitating the production of lactose-reduced or lactose-free products for individuals with lactose intolerance. Its inclusion enhances product accessibility and provides options for health-focused consumers. (Ericha et al., 2015; Mobayed et al., 2021).

Catalase

Catalase enzyme in the dairy industry plays a significant role in improving milk quality and extending the shelf life of dairy products (Silva et al., 2007). Therefore, ongoing research and development in catalase enzyme utilization in the dairy sector continue to bring innovation and improved quality to the industry. The areas of use of the catalase enzyme in the dairy industry are as follows:

Prevention of oxidation: Catalase enzyme breaks down peroxide compounds present in milk, thus preventing oxidative reactions. This reduces milk oxidation, preserves dairy product quality, and prolongs shelf life. Catalase enzyme is particularly used to prevent lipid oxidation in fatty dairy products.

Colour and taste stabilization: Catalase enzyme prevents colour changes and taste deterioration in milk and dairy products, thereby maintaining their visual and sensory properties. For example, the use of catalase enzyme prevents undesired colour changes and taste alterations in cheeses and other dairy products.

Utilization in fermentation processes: Some dairy products, especially fermented ones like yogurt, can be processed with catalase enzyme during fermentation. This reduces the impact of oxygen during fermentation, enhances product quality, and prevents unwanted taste changes.

Controlled milk solution preparation: Catalase enzyme is used to control the oxygen level in milk solutions in certain processes. This is particularly important in cheese production, milk processing stages, and packaging processes to control oxidation effects.

Natural preservative: Catalase enzyme serves as a natural preservative, replacing synthetic preservatives and providing healthy and natural preservation in milk and dairy products (Sahu and Kashyap, 2024).

In conclusion, the catalase enzyme plays a crucial role in various aspects of the dairy industry, from preserving milk quality to enhancing the shelf life of dairy products. Its ability to prevent oxidation, stabilize colour and taste, and act as a natural preservative makes it a valuable tool in dairy processing. By incorporating catalase enzyme technology, dairy producers can ensure product integrity, meet quality standards, and provide consumers with safe and high-quality dairy products. Continued research and development in catalase enzyme applications will further advance the dairy industry's capabilities and contribute to sustainable and innovative practices in dairy processing.

Lysozyme

The lysozyme enzyme is an important enzyme that plays a significant role in the dairy industry and has various application areas (Al-Baarr et al., 2018).

Antimicrobial properties: The lysozyme enzyme plays a significant role in controlling microbial growth in milk and dairy products by breaking down the peptidoglycan layer of bacterial cell walls, thus extending the shelf life of these products.

Cheese production: Lysozyme enzyme serves as a protective agent in cheese production, especially in soft cheeses like white mould cheeses, preventing bacterial spoilage during the ripening process and improving texture and quality.

Yogurt and fermented products: Lysozyme enzyme is also used in yogurt and other fermented dairy products to control bacterial contamination, given the high risk of bacterial growth in such products, thus ensuring product quality.

Processing and packaging: Lysozyme enzyme finds application in processing and packaging stages of milk and dairy products to control bacterial growth and maintain product freshness and safety, particularly in long shelf-life products.

General use in the food industry: Besides dairy, lysozyme enzyme is widely used in the food industry overall, especially in canned and processed foods, to control bacterial growth and ensure product safety.

Natural preservative and health applications: Lysozyme enzyme acts as a natural preservative, reducing the need for synthetic preservatives. It also finds applications in health products and supplements due to its antibacterial and anti-inflammatory properties.

These applications highlight the versatility and importance of lysozyme enzyme in maintaining the quality, safety, and shelf life of dairy and food products, contributing to overall consumer satisfaction and health standards in the industry.

The lysozyme enzyme is an enzyme that can kill vegetative bacterial cells and inhibit the development of their spores in cheeses. This enzyme is used for this purpose due to its resilience, which enables it to produce effective results in cheeses.

Transglutaminase

The transglutaminase enzyme particularly enhances the emulsification property of milk proteins, leading to improved viscosity increase. This allows for the desired viscosity enhancement, such as achieving the desired structure and consistency in yogurts, where the transglutaminase enzyme is frequently used (Khan and Selamoglu, 2020). Research indicates that for optimal results in production, the transglutaminase enzyme should be added to the process simultaneously with the rennet enzyme (Abada, 2019).

This enzyme, which catalyzes the polymerization of milk proteins, is also used in products such as high-protein nutrition bars where dairy products are utilized.

However, some studies suggest that the use of transglutaminase enzyme in both dairy and bakery production has led to an increase in celiac disease cases. Therefore, it highlights the need for significant research in studies related to this enzyme (Cabrera-Chavez, 2009). Transglutaminase enzyme plays a crucial role in various applications within the dairy industry:

Cheese production: Transglutaminase enzyme is essential in cheese production as it facilitates the formation of cross-links between proteins, improving the texture and consistency of cheese. These

cross-links result in a firmer and more elastic cheese structure, making it easier to slice while enhancing unique flavour and texture characteristics in different cheese varieties.

Ice cream and frozen dairy products: Transglutaminase enzyme is utilized in ice cream and frozen dairy products to enhance their texture and consistency. By binding milk protein molecules together, the enzyme creates a stronger network, resulting in a creamier and smoother texture in ice cream and related products.

Yogurt and fermented products: In certain yogurt and fermented dairy products, transglutaminase enzyme is employed to improve texture and stability. By cross-linking milk proteins, the enzyme contributes to a more stable structure and creamier consistency, enhancing the overall quality and sensory experience of these products.

Processing milk proteins: Transglutaminase enzyme is also used in processing alternative milk products based on milk proteins. For example, in almond milk or soy milk products, transglutaminase enzyme can enhance the texture and stability, providing diversified and healthier milk alternatives.

Quality and shelf life: Transglutaminase enzyme plays a vital role in improving the quality and extending the shelf life of dairy products. By enhancing product durability and stability, it minimizes quality degradation during storage, ensuring that products remain fresh and maintain their quality for a longer period.

These insights demonstrate the diverse and significant roles of transglutaminase enzyme in enhancing product quality, texture, and shelf life across various segments of the dairy industry. As enzyme technology continues to advance, the utilization of enzymes like transglutaminase is expected to grow, contributing to increased product diversity and quality in the dairy sector.

Protease

Protease enzymes are proteins that break down other proteins into smaller peptides or amino acids. They play a crucial role in various biological processes by aiding in the digestion of proteins and improving their digestibility. In the dairy industry, protease enzymes are used for several purposes and have diverse applications (Naveed et al., 2021).

Cheese production: Protease enzymes are vital in cheese production. During the cheese-making process, these enzymes break down proteins (typically casein) present in milk into various peptides and amino acids. This enzymatic breakdown contributes significantly to the texture and flavour profile of cheese. Moreover, specific types of cheeses utilize protease enzymes to achieve unique taste and texture characteristics.

Extending shelf life: Proteases are employed to extend the shelf life of dairy products by breaking down proteins. This enzymatic action reduces the available medium for microbial growth, thus enhancing the preservation of products and keeping them fresh for a longer duration.

Processing and fermented products: Proteases are used in milk processing and the production of fermented dairy products. Particularly in fermented products like yogurt, protease enzymes aid in breaking down milk proteins, improving product viscosity, texture, and taste. They contribute to achieving a smooth and creamy consistency in such products.

Milk protein hydrolysis and supplements: Protease enzymes play a crucial role in milk protein hydrolysis processes, especially in the production of protein supplements for athletes and fitness enthusiasts. Through enzymatic hydrolysis, proteins are broken down into smaller peptides and amino acids, enhancing their digestibility and nutritional value.

Innovations in dairy products: Proteases are not limited to traditional dairy products but are also used in innovative dairy-based products. For instance, energy drinks or protein bars containing milk protein may utilize protease enzymes to improve taste, digestibility, and nutritional content.

Overall, protease enzymes have diverse applications in the dairy industry, contributing to product quality, flavour enhancement, nutritional value, and shelf-life extension. As enzyme technology advances, their usage is expected to grow further, leading to increased product variety and improved quality standards in the dairy sector.

Protease enzymes are typically used in cheese production to facilitate the formation of flavour compounds. These enzymes accelerate the cheese production process and contribute to reducing allergic components in milk to minimal levels. Therefore, they are frequently used in the production of infant foods. Aminopeptidases are particularly effective in promoting the formation of flavour compounds, reducing allergic substances in milk, and accelerating cheese production, providing optimal results.

The use of protease enzymes helps reduce the bitter taste resulting from hydrophobic amino acids released due to the breakdown of short peptides found in milk.

Enzyme Modified Cheese Technique

The enzyme-modified cheese (EMC) technique is a specialized approach in cheese production that uses specific enzymes to alter the cheese's properties.

Enzyme selection: Different enzymes like proteases, lipases, and peptidases are used based on desired modifications in cheese, breaking down proteins and fats for texture and flavour changes.

Process control: EMC requires precise control of enzyme concentration, pH, temperature, and duration for specific modifications in cheese.

Flavour modification: Enzymes enhance or develop specific flavours like savoury or umami notes by breaking down proteins into peptides and amino acids.

Texture enhancement: Targeting protein or fat molecules allows modification of cheese texture, creating smoother textures or enhancing meltability.

Customization and innovation: EMC enables manufacturers to create customized products meeting consumer preferences, fostering innovation with unique flavours and textures.

Quality control and standardization: Stringent quality measures ensure consistency in modified cheese production, including monitoring enzyme activity and shelf-life stability.

Applications in specialty cheeses: EMC is used in specialty and artisanal cheeses for distinct flavour profiles and textures, offering versatility in cheese manufacturing for niche products (Kendirici et al., 2020).

In conclusion, the enzyme-modified cheese (EMC) technique is a sophisticated method in cheese production that utilizes specific enzymes to tailor the properties of cheese according to desired characteristics. This technique allows for customized flavours, textures, and overall product quality, contributing to innovation and diversity in the cheese industry. By carefully controlling the enzyme application and quality parameters, manufacturers can meet consumer preferences while maintaining consistency and standardization in their cheese products. EMC plays a vital role in the production of specialty cheeses and fosters continuous improvement and adaptation in response to market demands and technological advancements.

Conclusion

Various enzymes used in the dairy industry play a crucial role in the sector's development and the enhancement of quality standards. These enzymes are utilized across a wide range of processes, from cheese production to yogurt processing, to increase the nutritional value of products, improve taste and textures, and extend shelf life. Additionally, enzyme technology increases efficiency in production processes, reduces waste, and minimizes environmental impact. Future research and innovations are poised to further optimize the use of enzymes in the dairy industry, aligning them with sustainability principles and enhancing the sector's competitiveness. Advances in biotechnology and enzyme engineering will facilitate the development of more effective, eco-friendly, and tailored enzymes. This development will not only diversify dairy product offerings but also provide greater flexibility to meet consumer demands.

When we look at the commercial enzyme sector worldwide, it holds a significant market share. All these research and studies indicate that the dairy sector has a substantial presence within this share. Research in this advanced sector has progressed significantly at a scientific level. Foods containing these components have gained value, especially with the concept of functionality. For instance, the enzyme Cellobiose-2-epimerase has started to be preferred in the dairy industry due to its ability to break down lactose into epimeric and isomeric forms. This is because these epimeric forms, namely epilactase and lactulose, are candidates for functional food materials. Particularly, lactulose is under research due to its potential positive effects on diseases related to diabetes and intestinal functions. Future research on enzymes is expected to focus on obtaining enzymes that are more economical and produced in a shorter time while also obtaining different functional properties, which would contribute to human health and the improvement of diseases. In conclusion, the growing importance of enzyme technology in the dairy industry is driving successful progress in the sector. The advantages derived from enzyme use, such as increased efficiency, improved quality, and environmental compatibility, will support the industry's future growth and transition towards sustainability.

References

- Abada, E., 2019. Application of microbial enzymes in the dairy industry. *Enzymes in Food Biotechnology*. 61-72.
- Al-Baarri, A. N. M., Legowo, A. M., Arum, S. K., Hayakawa, S., 2018. Extending shelf life of Indonesian soft milk cheese (dangke) by lactoperoxidase system and lysozyme. *International Journal of Food Science*.
- Cabrera-Chavez, F., Rouzaud-Sandez, O., Sotelo-Cruz, N., Calderon de la Barca, A. M., 2009. Bovine milk caseins and transglutaminase-treated cereal prolamins are differentially recognized by IgA of celiac disease patients according to their age. *Journal of agricultural and food chemistry*. 57 (9): 3754-3759.
- Chen, Q., Wu, Y., Huang, Z., Zhang, W., Chen, J., Mu, W., 2022. Cold-active enzymes in the dairy industry: Insight into cold adaptation mechanisms and their applications. *Trends in Food Science & Technology*. 125: 126-135.
- Ericha, S., Kuschela, B., Schwarza, T., Ewerta, J., Bohmera, N., Niehaus, F., Eckb, J., Lutz-Wahla, S., Stressler, T., Fischer, L., 2015. Novel high-performance metagenome-galactosidases for lactose hydrolysis in the dairy industry. *Journal of Biotechnology*. 210: 27-37.
- Fallahi, P., Habte-Tsion, H. M., Rossi, W., 2018. Depolymerizing enzymes in human food: bakery, dairy products, and drinks. In *Enzymes in human and animal nutrition*. 211-237.
- Kendirci, P., Salum, P., Bas, D., Erbay, Z., 2020. Production of enzyme-modified cheese (EMC) with ripened white cheese flavour: II-effects of lipases. *Food and Bioproducts Processing*. 122: 230-244.
- Khan, M., Selamoglu, U., 2020. Use of enzymes in dairy industry: A review of current progress. *Archives of Razi Institute*. 75 (1): 131-136.
- Kittibunchakul, S., Pham, M.L., Tran, A.M., Nguyen, T.H., 2019. Galactosidase from *Lactobacillus helveticus* DSM 20075: Biochemical characterization and recombinant expression for applications in dairy industry. *Int. J. Mol. Sci*. 20: 947.
- Kocabas, D.S., Lyne, J., Ustunol, Z., 2022. Hydrolytic enzymes in the dairy industry: Applications, market and future perspectives. *Trends in Food Science & Technology*. 119: 467-475.
- Li, Y., Liang, S., Zhi, D., Chen, P., Su, F., Li, H., 2012. Purification and characterization of *Bacillus subtilis* milk-clotting enzyme from Tibet Plateau and its potential use in yak dairy industry. *Eur Food Res Technol*. 234: 733-741.
- Mobayed, F., Nunes, J.C., Gennari, A., Andrade, A.D., Ferreira, M.L.V., Pauli, P., Renard, G., Chies, J.M., Volpato, G., Volken, C.F., 2021. Effect of by-products from the dairy industry as alternative inducers of recombinant b-galactosidase expression. *Biotechnol Letter*. 43: 589-599.
- Naveed, M., Nadeem, F., Mehmood, T., Bilal, M., Anwar, Z., Amjad, F., 2021. Protease—a versatile and ecofriendly biocatalyst with multi-industrial applications: an updated review. *Catalysis Letters*. 151: 307-323.
- Silva, C. R. D., Delatorre, A. B., Martins, M. L. L., 2007. Effect of the culture conditions on the production of an extracellular protease by thermophilic *Bacillus* sp and some properties of the enzymatic activity. *Brazilian Journal of Microbiology*. 38: 253-258.
- Singh, R., Singh, A., Sachan, S., 2019. Enzymes used in the food industry: Friends or foes? In *Enzymes in Food Biotechnology*. Elsevier: Amsterdam. The Netherlands. 827-843.
- Srivastava, N., 2019. Production of food-processing enzymes from recombinant microorganisms. In *Enzymes in food biotechnology*. Academic Press. 739-767.