LACTOSE-FREE DAIRY PRODUCTS

Abstract

Lactose hydrolysed dairy products have grown popularity in recent years, particularly among lactose intolerant people. Their production, however, poses a number of challenges and opportunities for the food industry. The hydrolysis process involves the controlled breakdown of lactose into glucose and galactose using specific enzymes. Choosing the right enzymes and process parameters is critical for achieving optimal hydrolysis and minimising the formation of undesirable compounds that can have an impact on the product's quality and properties. Furthermore, using lactose-free milk as a starting material has an impact on processing steps and sensory properties. Producing lactose hydrolysed dairy products necessitates specialised equipment and facilities, which can be prohibitively expensive for small and medium-sized businesses. Furthermore, shelf-life and stability can be difficult because they are more prone to browning and Maillard reactions, as well as microbial spoilage. Despite this, the demand for lactose-free dairy products provides opportunities for the food industry to develop new and innovative products. Lactose hydrolysed dairy products have the potential to provide health benefits such as improved digestion and nutrient absorption, which can be marketed to health-conscious consumers. Creating value-added products, such as lactose-free cheese and ice cream, can also help to attract new customers and boost profits. To summarise, the production of lactose hydrolysed dairy products necessitates careful consideration of several factors, including the selection of appropriate enzymes, process parameters, and raw materials, as well as the use of specialised equipment and facilities. The potential health benefits and market opportunities for these products make them an appealing option for the food industry to

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investigate. Nonetheless, ongoing research and development are required to improve quality, stability, and cost-effectiveness in order to meet the changing needs of consumers.

Keywords: lactose hydrolysed dairy products, lactose intolerance, enzyme, shelf-life, value-added products, food industry, market opportunities.

I. INTRODUCTION

Milk is a complex fluid and is considered a rich source of fat, carbohydrates, proteins, minerals, and more. Lactose is the main carbohydrate found in milk. Human milk contains approximately 7% lactose, while bovine milk contains 4.5-5.0%, contributing 30% of the total calorie content in bovine milk. Lactose is a significant source of energy for human infants, providing nearly half of their total energy requirement. It is a disaccharide consisting of glucose and galactose linked by a β-1,4-galactosidase bond. It plays a crucial role in biological functions, such as stimulating the growth of *Bifidobacterium*. It also helps maintain the osmotic pressure between milk and blood. The solubility of lactose is 13g/100g of an aqueous solution at 10ºC, while glucose and galactose have solubilities of 40g/100g and 28g/100g, respectively (Belitz et al. 2001). Lactose hydrolysed dairy products have grown in popularity in recent years due to their lower lactose content, making them suitable for lactose intolerant people. However, the manufacturing of these products presents a number of processing challenges and opportunities (Dekker et al. 2019). The hydrolysis process necessitates the use of specific enzymes and conditions that influence the final product's quality and properties. Furthermore, the use of lactose-free milk may affect the processing steps as well as the sensory properties of the product (Matijević et al. 2011). The demand for lactose-free dairy products, on the other hand, presents an opportunity for the food industry to develop new and innovative products that meet the needs of consumers. Furthermore, lactose hydrolysed dairy products may have health benefits such as improved digestion and nutrient absorption, which can be marketed to attract the attention of health-conscious consumers (Suri et al. 2019). Overall, lactose hydrolysed dairy product processing necessitates careful consideration of several factors in order to produce high-quality products that meet consumer expectations.

II. LACTOSE INTOLERANCE

Lactose intolerance in the human population is mainly caused by the absence of lactase enzymes, which convert lactose into glucose and galactose for digestion. Without sufficient lactase, infants and individuals cannot properly digest lactose, leading to unpleasant symptoms such as gas, bloating, and diarrhea. Lactose intolerance is a common problem in both children and adults worldwide, affecting over 70% of the global population. In India, approximately 53% of individuals are unable to digest lactose due to a lack of β-D-galactosidase enzymes (Ugidos-Rodríguez et al. 2018). Lactose-intolerant individuals are predominantly found in eastern and southern India (Johnson 1993). Lactose has hygroscopic properties and tends to absorb flavors and odors, causing defects like lactose crystallization in frozen dairy products. Enzymatic hydrolysis can help alleviate lactose-related issues. Commercial lactose-free milk contains less than 0.25g of lactose per 100g of milk, achieved through the enzymatic hydrolysis of lactose into glucose and galactose. The lactose levels in milk range from 4–5g/100ml. Glucose and galactose resulting from lactose hydrolysis are 50% sweeter than unhydrolyzed milk (Zadow 1991). About 40% of children aged two to five cannot produce sufficient lactase enzyme and due to which, they are unable to digest lactose form cow's milk (Martin et al. 2016). Diagnosis of lactose intolerance in children is based on abdominal symptoms, which vary depending on lactose intake. It is vital to mention that, children who are lactose intolerant are often found at the risk of vitamin D and calcium deficiencies, and thus in order to combat these effects they must take foods for special health use particularly rich in calcium and vitamin D (Sekar et al. 2020).

III. LACTOSE INTOLERANCE CAN BE CATEGORIZED INTO THREE TYPES

Congenital lactase deficiency is a rare genetic condition characterized by the complete absence or significant reduction of the lactase enzyme. It manifests from birth and persists throughout a person's life. By diagnosing it early and implementing a lactose-free diet, severe symptoms can be prevented (Kuokkanen et al. 2006).

1. **Developmental Lactase Deficiency:** Developmental lactase deficiency occurs in premature infants due to low levels of lactase. However, this deficiency is compensated for by colonic bacterial metabolism, which helps prevent diarrhea and malnutrition. As the colonic pH decreases, it favors the colonization of other microbial species like *Bifidobacterium* or *Lactobacillus*, thereby preventing diarrhea and malnutrition in infants (Heyman and Committee on Nutrition 2006).

2. **Primary Lactase Deficiency or Adult Hypolactasia:** Primary lactase deficiency or as adult hypolactasia, is the most prevalent type of lactose intolerance, which is characterized by progressive decline in the lactase activity. The symptoms experienced vary depending on the level of lactase persistence. Typically, primary lactase deficiency emerges between the ages of 5 and 7, with the greatest impact occurring between 30 and 40 years of age (Beja-Pereira et al. 2003).

3. **Secondary Lactase Deficiency:** Secondary lactase deficiency arises due to various factors, such as chronic enteropathy (e.g., celiac disease), malnutrition, or gastrointestinal diseases that damage the small intestine (Sharp et al. 2021). Lactase activity decreases temporarily in such cases and can be reversed when the underlying condition is treated. Geographical variability exists in the prevalence of lactose intolerance, with higher rates observed in Asian and African populations, and lower rates in Europeans. Several hypotheses propose that historical, environmental factors, and genetic mutations have influenced lactose tolerance patterns across different populations (Mishkin 1997).

IV. IMPORTANCE OF LACTOSE HYDROLYSED DAIRY PRODUCTS

Lactose-hydrolysed dairy products are important for people who are lactose intolerant. Lactose intolerance is a common condition that affects up to 75% of the world's population, and it can cause digestive problems such as, flatulence, bloating and diarrhoea (Di Rienzo et al. 2013). By consuming lactose-hydrolyzed dairy products, individuals with lactose intolerance can reap the nutritional benefits of dairy without encountering symptoms. Lactose-hydrolysed dairy products are decent sources of these nutrients and can help people with lactose intolerance meet their daily requirements (Suri et al. 2019).

V. THE POPULARITY OF LACTOSE HYDROLYSED DAIRY PRODUCTS

The popularity of lactose-hydrolysed dairy products has increased in recent years. According to a recent report by Grand View Research, the global lactose-free market size reached a value of USD 10.89 billion in 2020, with projected compound annual growth rate (CAGR) of 9.2% from 2021 to 2028. This progression could be owing to the rising occurrence of lactose intolerance thereby leading to a surge in lactose-free products' demand (Dekker et al. 2019). Lactose-hydrolyzed dairy products have gained popularity among

athletes and fitness enthusiasts as well. Lactose-hydrolyzed dairy products offer an alternative for individuals who are lactose intolerant but still wish to benefit from the nutritional advantages of dairy consumption. These products serve as an essential and popular substitute for lactose-intolerant individuals, providing them with necessary nutrients like calcium and vitamin D, without causing digestive issues. The escalating demand for lactose-free products has resulted in the development of a wide range of lactose-hydrolyzed dairy products, which are readily available in supermarkets and health food stores.

VI. PROCESSING STRATEGIES FOR LACTOSE HYDROLYSED PRODUCTS

Lactose-hydrolyzed goods are typically processed using enzymatic hydrolysis of lactose to break it down into its constituent sugars, glucose and galactose. Here are some popular lactose-hydrolyzed product manufacturing strategies:

1. **Enzymatic Hydrolysis:** The first stage in processing lactose-hydrolyzed products is to break down lactose into simpler sugars using enzymes such as lactase. This is accomplished by incorporating lactase into the product and allowing it to catalyse the hydrolysis reaction (Bulgaru et al. 2019). To optimise lactose conversion, the reaction is often carried out under temperature, pH, and time control. Enzymatic hydrolysis is critical in the production of lactose-hydrolyzed products. The primary goal of this stage is to convert lactose, a disaccharide made of glucose and galactose, into simpler sugars that are more easily digestible, often with the help of enzymes such as lactase. Lactase, which is added to the product, catalyses the hydrolysis step, turning lactose to its constituent monosaccharides (glucose and galactose). Temperature, pH, and reaction time are all carefully managed to promote optimal lactose conversion (Albayrak and Yang 2001). These elements are critical for increasing the activity and efficiency of the lactase enzyme. The temperature and pH settings change depending on the enzyme's properties and the desired end product. At the right temperature and pH, enzyme activity is increased during enzymatic hydrolysis without being denatured. Adequate reaction time allows the enzyme to interact with lactose, aiding its breakdown. The reaction time of an enzymatic process is determined by its kinetics, which can be affected by variables including the concentrations of the enzyme and substrate as well as the desired degree of lactose hydrolysis. Enzymatic hydrolysis efficiently transforms lactose into glucose and galactose by carefully controlling these parameters, resulting in a final product that is suitable for people with lactose sensitivity or dietary restrictions. Enzymatic hydrolysis has benefits over chemical hydrolyses, such as milder processing conditions and better product quality (Carvalho et al. 2013; Kocabaş et al. 2022). Aiming to increase lactose conversion efficiency, increase enzyme stability, and lower the cost of enzymatic systems, ongoing research and development aims to make lactose-hydrolyzed products more accessible and affordable for people with lactose intolerance or special dietary needs.

2. **Ultrafiltration**: The lactose-hydrolyzed product may be ultrafiltered after enzymatic hydrolysis (Harju et al. 2012). This method includes passing the solution through a membrane with a specified hole size that allows smaller molecules like glucose and galactose to flow through while keeping larger molecules like proteins and lipids out. Ultrafiltration is a crucial process that separates and concentrates hydrolyzed sugars in two ways by removing proteins and lipids, enabling the isolation and concentration of glucose and galactose, while also allowing smaller molecules to pass through the

membrane, resulting in a more concentrated sugar solution (McCain et al. 2018). The selection of an appropriate membrane pore size is crucial to retain undesired components while allowing glucose and galactose molecules to pass through, ensuring the effectiveness of ultrafiltration in producing high-quality lactose-free products and expanding dietary options for individuals with lactose intolerance or dietary restrictions (Zhang et al. 2020).

3. **Heat Treatment**: Heat treatment is an essential step in the production of lactose-hydrolyzed products, serving multiple purposes and offering several advantages. Once the desired degree of hydrolysis is achieved through enzymatic action, heat can be applied to deactivate the lactase enzyme and prevent excessive lactose conversion, preserving the sensory characteristics of the final product (Yılmaz-Karaoğlu et al. 2022). Furthermore, heat treatment contributes to product sterilization, eliminating potential microbes and extending the shelf life. It also enhances sensory properties, such as taste, texture, and mouthfeel, by creating or enhancing flavor compounds (Dhankhar and Kundu 2021). However, it is crucial to carefully optimize heat treatment parameters to avoid negative effects on product quality, such as protein denaturation or nutrient loss. By controlling heat treatment settings, manufacturers can ensure safety, quality, and extended shelf life of lactose-hydrolyzed products.

4. **Filtration and Clarification:** Filtration and clarifying are critical processes in the lactose-hydrolyzed product manufacturing to assure the elimination of any leftover impurities, suspended particles, or undesirable components (Qi et al. 2022). Microfiltration and centrifugation are essential techniques in achieving a clear and high-quality lactose-hydrolyzed product. Microfiltration involves passing the solution through a membrane with sized pores, effectively removing particles, bacteria, and suspended solids while allowing sugars to flow through. This ensures clarity and purity by eliminating contaminants (Gul et al. 2021). Centrifugation separates solid and liquid phases in the lactose-hydrolyzed solution, with denser particles settling at the bottom, resulting in a clarified product. Filtration and clarification stages enhance product quality and appearance by eliminating impurities, improving clarity, visual appeal, purity, consistency, and extending shelf life (Tommaso et al. 2012). The risk of spoiling and microbial growth is reduced by eliminating contaminants and germs, improving the product's stability and safety during storage and distribution.

   It is important to note that the filtration method used is determined by a variety of criteria, including the type of the lactose-hydrolyzed product, the required degree of clarity, and the equipment available. Manufacturers can choose the best filtration technology based on factors such as cost-effectiveness, efficiency, and desired final product attributes.

5. **Concentration:** Concentration is vital in processing lactose-hydrolyzed products, achieved through methods like evaporation or reverse osmosis (Wijayasinghe et al. 2015). Evaporation involves heating the solution to evaporate water and obtain a more concentrated product with higher glucose and galactose levels. Reverse osmosis utilizes pressure and a semipermeable membrane to selectively remove water, resulting in increased concentration (Deshwal et al. 2021). Concentration offers advantages such as adjusting sweetness to meet specific taste preferences and catering to applications

requiring desired levels of sweetness. Furthermore, concentration has an effect on the viscosity and texture of the product. Higher sugar concentrations can contribute to higher viscosity, resulting in a thicker and more substantial mouthfeel (Thun et al. 2022). This can be used in a variety of food applications when a specific texture or thickness is desired, such as when making sweets, yoghurt, or ice cream. It is vital to highlight that concentration should be carefully maintained to avoid excessive sugar levels or changes in the sensory properties of the final product. To achieve the desired concentration while retaining product quality and sensory qualities, concentration parameters such as temperature, time, and equipment settings must be properly optimised.

VII. LACTOSE HYDROLYSIS KINETICS

The kinetics of lactose hydrolysis involves studying the rate of hydrolysis over time, considering factors like lactose content and lactase enzyme activity. The Michaelis-Menten model is commonly used to describe lactose hydrolysis kinetics, relating the rate of hydrolysis to lactose and enzyme concentrations (Kaczyński et al. 2019). The model indicates that the rate initially increases with lactose concentration but reaches a maximum reaction rate (Vmax). The Michaelis constant (K_m) represents the substrate concentration, where the reaction rate is $V_{max/2}$, providing insights into enzyme efficiency. Other kinetic models may incorporate additional factors such as enzyme and product inhibition, pH, temperature, and interfering chemicals. Understanding lactose hydrolysis kinetics helps optimize reaction conditions, enzyme concentration, and substrate utilization for improved lactose conversion rates and production efficiency (Thum et al. 2019).

VIII. RESIDUAL LACTOSE AND ITS MEASUREMENT

Consumption of lactose-containing dairy products can cause symptoms such as abdominal cramps or pain, bloating, gas, and diarrhea in lactose-intolerant individuals. To cater to the dietary needs of this population while providing calcium and high-quality protein, the dairy industry has developed lactose-free products by adding exogenous lactase, specifically β-galactosidase. However, there is no global consensus on the lactose concentration that defines a dairy product as lactose-free. Different countries have different thresholds, such as <0.1% (w/w) or <0.01% (w/w) in certain European countries and <0.5% (w/w) in China (EFSA 2010). Residual Lactose is the amount of Lactose that remains in a product after hydrolysis. The amount of residual Lactose is usually expressed as a percentage. Several different methods can measure the amount of residual Lactose. The most common method is the polarimetric method. The polarimetric way measures the amount of optical rotation of a solution, which is directly proportional to lactose concentration. Recent research has focused on innovative methods for quantifying low-level lactose in milk. Gas chromatography, ultra-high-performance liquid chromatography coupled with tandem mass spectrometry (UHPLC-MS/MS), high-performance thin-layer chromatography with fluorescence detection (HPTLC-FLD), and nuclear magnetic resonance (NMR) have demonstrated impressive limits of detection (LODs) (Gille et al. 2018; Idda et al. 2016; Monakhova et al. 2012; Morlock et al. 2014; Trani et al. 2017).

IX. NUTRITIONAL AND HEALTH CONSIDERATIONS

Lactose is a sugar found in milk and dairy products, and it is broken down into glucose and galactose by the enzyme lactase. The cells lining the small intestine produce lactase enzyme. However, some people do not produce enough lactase, which can lead to lactose intolerance. Lactose intolerance is when people experience bloating, gas, diarrhoea, and abdominal cramps after consuming dairy products. Lactose-hydrolysed dairy products offer the same nutritional value as regular dairy products by being noble sources of protein, calcium and other nutrients. Lactose-free products are also a good option for people who are lactose intolerant. Lactose-hydrolysed dairy products are dairy products that have lactose broken down into glucose and galactose, and this makes them easier to digest for people who are Lactose intolerant. However, lactose-hydrolysed dairy products can be more expensive than regular dairy products and may be less widely available.

X. HEALTH BENEFITS OF LACTOSE-FREE PRODUCTS

There are several health benefits to consuming lactose-free products. These benefits include:

1. **Improved Digestibility:** Lactose-free products are easier to digest for people who are lactose intolerant. This is because the lactose has already been broken into glucose and galactose.
2. **Reduced Risk of Symptoms:** Consuming lactose-free products can help to reduce the risk of symptoms associated with lactose intolerance, such as bloating, gas, diarrhoea, and abdominal cramps.
3. **Good Source of Nutrients:** Lactose-free products offer balanced nutrition.
4. **Variety of Options:** Lactose-free products are available in various forms, including milk, yoghurt, cheese, and ice cream. This makes it easy to find lactose-free options that fit personal dietary needs and preferences (Skryplonek et al. 2017).

XI. CONCERNS ABOUT LACTOSE-FREE PRODUCTS

There are a few concerns about lactose-free products. These concerns include:

1. **Cost:** Lactose-free products can be more expensive than regular dairy products.
2. **Availability:** Lactose-free products may not be as widely available as regular dairy products.
3. **Taste:** Some people find that lactose-free products taste different from regular dairy products.

Lactose-free products offer several benefits for people who are Lactose intolerant or who are trying to reduce their intake of sugar. However, lactose-free products can be more expensive and less widely available than regular dairy products. Some people also find that lactose-free products taste differently than regular dairy products (Costa et al. 2019; Suri et al. 2019).

XII. CHALLENGES IN LACTOSE HYDROLYSIS

The key challenges in lactose hydrolysis include:

1. The need to use a high lactase concentration to achieve complete hydrolysis.
2. The need to operate at a high temperature to achieve a rapid rate of hydrolysis.
3. The need to control the pH to prevent the formation of Maillard products.
4. The need to remove residual lactose to achieve a product suitable for lactose-intolerant individuals.

Despite these challenges, lactose hydrolysis is a valuable process that can be used to produce a variety of lactose-free products (Hodges et al. 2019).

XIII. SHELF-LIFE AND STABILITY OF LACTOSE-FREE PRODUCTS

The shelf-life and stability of lactose-free products depend on processing methods, ingredients, and storage conditions. Enzymatic hydrolysis is preferred for long shelf-life, while thermal hydrolysis may result in shorter shelf-life (Bottiroli et al. 2020). Ingredients like sugar alcohols can increase stickiness, while artificial sweeteners may degrade and taste bitter over time. Storage at high temperatures can reduce shelf-life. Despite challenges, lactose hydrolysis is valuable for producing various lactose-free products offering improved digestibility and reduced risk of lactose intolerance symptoms (Dekker et al. 2019).

XIV. MARKET DEMAND AND CONSUMER PREFERENCE

The global market for lactose-hydrolysed dairy products is expected to grow at a CAGR of 5.1% from 2022 to 2027. Also, the Indian market is expected to grow at a CAGR of 10% from 2022 to 2027. The growth of this market is driven by the increasing prevalence of lactose intolerance, the growing awareness of the health benefits of dairy products, and the increasing availability of lactose hydrolysed dairy products. The availability of lactose-hydrolysed dairy products is increasing. This is due to the growing demand for these products and the development of new technologies for producing lactose-hydrolysed dairy products. Consumer preferences for lactose-hydrolysed dairy products are also increasing. This is due to the increasing awareness of the health benefits of dairy products and the increasing availability of these products.

Here are some of the key consumer preferences for lactose-hydrolysed dairy products:

1. **Taste:** Consumers want lactose-hydrolysed dairy products that taste good.
2. **Price:** Consumers want lactose-hydrolysed dairy products that are affordable.
3. **Convenience:** Consumers want lactose-hydrolysed dairy products that are convenient to use.
4. **Health Benefits:** Consumers want lactose-hydrolysed dairy products that offer health benefits.

The lactose-hydrolysed dairy products market is expected to grow in the coming years. This is due to the increasing prevalence of lactose intolerance, the growing awareness of the health benefits of dairy products, and the increasing availability of

lactose hydrolysed dairy products. The following are some of the key players in the global market for lactose-hydrolysed dairy products: Abbott Laboratories, Danone, Nestle, Friesland Campina, Arla Foods, Dean Foods, Kraft Foods, Unilever, Yakult Honsha and Morinaga Milk Industry. These companies invest in research and development to develop new and innovative lactose-hydrolysed dairy products. They are also expanding their distribution networks to reach a wider range of consumers (Harju et al. 2012).

XV. CONSUMER'S ATTITUDE AND MARKETING STRATEGIES TOWARDS LACTOSE-FREE PRODUCTS

Consumer attitude towards lactose-free products in the Indian market is generally positive. These products are seen as convenient and reliable for obtaining nutrients from dairy without lactose intolerance concerns. A recent study by the Indian Dairy Association revealed that 75% of Indian consumers are aware of lactose intolerance, and 60% of those aware have tried lactose-hydrolyzed dairy products. Furthermore, the study found that consumers who have tried these products are more satisfied compared to those who haven't. Factors contributing to this positive attitude include increasing lactose intolerance awareness, greater availability of lactose-hydrolyzed dairy products, and the perceived health benefits associated with easier digestion. This positive consumer outlook indicates potential market growth as awareness and product trials continue to rise.

Effective marketing strategies for lactose-free products can include:

1. Educating consumers about lactose intolerance to help them understand symptoms and the availability of lactose-free alternatives.
2. Emphasizing the health benefits of lactose-free products, such as their nutritional value and contribution to calcium, protein, and other essential nutrients.
3. Prominently displaying lactose-free products in stores to enhance visibility for consumers seeking them.
4. Offering discounts and promotions to make lactose-free products more affordable and encourage trial.
5. Collaborating with lactose-intolerant influencers to expand awareness and reach a broader audience.

XVI. EMERGING AND INNOVATIVE SOLUTIONS FOR EFFECTIVE LACTOSE HYDROLYSIS

1. **Enzyme Engineering:** Researchers are continually attempting to improve the efficiency and specificity of lactase enzymes utilised in lactose hydrolysis. Enzymes with increased catalytic activity, stability, and substrate selectivity are being produced through genetic changes and protein engineering.

2. **Bioprocessing Technologies:** Novel bioprocessing technologies for lactose hydrolysis are being investigated. This includes the use of immobilised enzyme systems to improve enzyme stability, reusability, and separation efficiency, such as enzyme immobilisation on solid supports or encapsulation in biocompatible materials.

3. **Membrane-based Technologies:** Membrane-based technologies for lactose hydrolysis and separation processes are gaining popularity. Membrane reactors, such as membrane bioreactors or membrane-assisted enzyme reactors, are examples of these, as they combine enzymatic hydrolysis and separation in a single step. Membrane filtering techniques like nanofiltration and pervaporation are also utilised to selectively separate and concentrate hydrolysed sugars.

4. **Advanced Chromatography:** Chromatographic techniques such as ion exchange or affinity chromatography are being used to purify and separate lactose-hydrolysed products. These methods provide high purity and selective sugar separation, allowing for the creation of specific sugar profiles or customised products.

5. **High-Pressure Processing (HPP):** High-pressure processing is being investigated as a non-thermal lactose hydrolysis method. By applying high pressures to the enzyme-substrate mixture, HPP can improve the hydrolysis reaction, resulting in increased enzymatic activity and shorter reaction durations.

6. **Hybrid Processing Approaches:** To optimise lactose hydrolysis, hybrid processing approaches that incorporate different technologies are being developed. Combining enzymatic hydrolysis with other processes, such as ultrasonication, microwave heating, or pulsed electric fields, for example, can improve the efficiency and speed of the hydrolysis reaction.

7. **Microreactor Systems:** Microreactor systems provide fine control over reaction parameters as well as shorter reaction periods. These small-scale devices enable quick mixing and effective heat and mass transmission, resulting in better lactose enzymatic hydrolysis.

8. **Process Intensification:** To improve the efficiency, productivity, and sustainability of lactose hydrolysis operations, process intensification strategies such as continuous flow processing, intensified reactor designs, or integrated process configurations are being adopted.

9. **Advanced Analytical Techniques:** To monitor the lactose hydrolysis process, advanced analytical techniques such as online monitoring, spectroscopy, and real-time sensing technologies are applied. These methods provide real-time data on reaction progress, enzyme activity, and product quality, allowing for accurate process control and optimisation.

XVII. POTENTIAL HEALTH BENEFITS AND FUNCTIONAL PROPERTIES OF LACTOSE-FREE PRODUCTS

Lactose-free products offer many potential health benefits and functional properties. These benefits include:

1. **Improved Digestion:** Lactose-free products are easier for people with lactose intolerance. This is because Lactose has been broken down into glucose and galactose, smaller sugars

that are easier to digest.

2. **Reduced Bloating and Gas:** Lactose-free products can help to reduce bloating and gas in people with lactose intolerance. This is because Lactose has been broken down into glucose and galactose, which are less likely to cause these symptoms.

3. **Improved Nutrient Absorption:** Lactose-free products can help improve nutrient absorption, such as calcium and magnesium. This is because Lactose has been broken down into glucose and galactose, which are more easily absorbed by the body.

4. **Increased Satiety:** Lactose-free products can help to increase satiety, which can help people to eat less and lose weight. This is because lactose-free products are often lower in calories than dairy products that contain Lactose.

Lactose-free products are a good choice for people with lactose intolerance or other digestive problems. They are also a good choice for people looking for a healthier alternative to dairy products containing Lactose.

XVIII. CONCLUSION

Lactose hydrolysis is an important process for the production of lactose-free products, breaking down lactose into glucose and galactose. While there are challenges involved, such as the use of high lactase concentrations, operating at elevated temperatures, controlling pH, and removing residual lactose, lactose hydrolysis remains a viable method to create safe and enjoyable lactose-free products for individuals with lactose intolerance. The dairy industry can seize a promising market opportunity with lactose-free products. Lactose intolerance is a prevalent condition affecting a significant portion of the global population, presenting a large potential consumer base. By offering lactose-free options, the dairy industry can cater to a broader range of consumers and boost sales. For consumers, lactose-free products bring several benefits. They provide an easier-to-digest alternative for those with lactose intolerance, allowing them to enjoy dairy products without experiencing associated symptoms. Additionally, lactose-free products serve as a healthier option for individuals seeking alternatives to lactose-containing dairy products, often featuring lower calorie and fat content. The advantages offered by lactose-hydrolyzed dairy products benefit both the dairy industry and consumers, expanding market reach and providing a healthier choice for lactose-intolerant individuals.

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