

Biocatalyst Production Technology and their Application in the Food Industry

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Annotation: Biocatalysts play a crucial role in modern food biotechnology, offering sustainable and efficient alternatives for industrial processing. This study examines the extraction, purification, activity analysis, immobilization, and application of biocatalysts in the food industry. Enzyme purification was optimized using ion-exchange chromatography and heterofiltration, ensuring high purity and activity. Activity tests revealed that most enzymes performed optimally at temperatures between 35-45°C and pH levels of 5.5-7.5. Immobilization techniques, particularly covalent bonding and encapsulation, improved enzyme stability and reusability. Experimental applications demonstrated that biocatalysts enhance dough structure in baking, promote lactose hydrolysis in dairy, improve meat tenderness, and facilitate juice clarification. The study confirms the effectiveness of biocatalysts in food processing and highlights their potential for sustainable industrial applications.

Keywords: Biocatalysts, enzyme extraction, immobilization, food processing, enzyme stability, biotechnology, industrial enzymes, fermentation, food quality, sustainable processing.

INTRODUCTION

The implementation of environmentally safe, efficient, and energy-saving technologies in modern food industries is of great importance. From this perspective, the use of biocatalysts represents one of the innovative solutions for industrial processes. Biocatalysts are catalysts based on enzymes or living cells, widely used to accelerate chemical reactions and improve product quality.

The scientific work by Kirk and Othmer extensively covers the significance of biocatalysts in the fields of chemistry and industry, providing detailed information on the fundamental principles of biochemical processes, the mechanisms of enzyme function, and their role in industrial biotechnology. In particular, the study analyzes the impact of enzymes on natural substances in the food industry and the methods for their extraction [1].

Studies dedicated to the principles of enzyme application in industrial processes highlight the role of enzymes in food processing, their advantages over traditional chemical catalysts, and their environmental safety. Specific examples of enzyme applications in the production of bread, dairy products, meat, and beverages are presented in the research [2].

Additionally, scientific articles and studies explore the significance of biocatalysts in biotechnology, analyzing methods for producing enzymes through natural and recombinant DNA technologies. These works provide essential scientific evidence regarding the environmental safety and selectivity of biocatalysts [3].

Research on enzyme immobilization and its industrial application mechanisms focuses on the long-term efficiency of biocatalysts and their reusability in industrial-scale processing. These studies demonstrate the potential to enhance industrial process efficiency, reduce energy consumption, and minimize environmental impact [4].

Furthermore, the practical aspects of biocatalysis remain an important research area, examining how enzymes are used in food technology, their energy-saving properties, and environmental benefits.

Scientific studies in this field are closely related to enzyme-based food processing, the production of biological preservatives, and waste management [5].

Research dedicated to the theoretical and practical aspects of enzymatic processes demonstrates the efficiency of biocatalysts compared to traditional technologies, allowing for a deeper understanding of their role in the food industry [6]. At the same time, scientific studies on microbial enzyme production and their integration into biotechnology help identify new approaches in this field [7].

Studies on the application of enzymes in food processing, their impact on technological processes, and their role in improving production efficiency provide detailed insights into how enzymes enhance the physicochemical properties of dough, stabilize the structure of dairy products, and extend the shelf life of food products [8].

In addition, scientific sources analyzing the chemical and biochemical effects of enzymes in food products, their biological significance, and their application in the food industry contribute to a deeper understanding of the importance of biocatalysts in industrial processes [9]. Research aimed at integrating modern enzymatic technologies into industrial production, making manufacturing processes more environmentally friendly, and increasing economic efficiency is also of great significance [10].

Furthermore, studies on the role of biocatalysts in enzyme synthesis, their application in various industrial sectors, and their connection with innovative biotechnologies provide valuable scientific insights [11]. In particular, research on the automation of biocatalysis, the development of new enzymatic systems through genetic engineering, and improvements in production efficiency make significant contributions to the advancement of industrial biotechnology [12-20]. Studies on the role of biocatalysis in pharmaceuticals, food production, agriculture, and environmental protection focus on enhancing the efficiency and sustainability of enzymatic processes [13]. The production of biomaterials, biologically active substances, and environmentally safe technologies based on enzymes creates new opportunities in industrial biotechnology [14]. Additionally, research highlights the methods for increasing the stability and durability of biocatalysts through immobilized enzymes and nanobiotechnologies [15-17]. At the same time, significant progress has been made in improving enzyme selectivity and activity using recombinant DNA technologies [18-20].

Biocatalysts play a crucial role in optimizing various technological processes in the food industry. For example, lactases assist in lactose breakdown in dairy processing, amylases enhance dough quality in bread production, and proteases function as meat tenderizers. Additionally, biocatalysts are used as preservatives, helping to extend the shelf life of food products.

Therefore, the production and application of biocatalysts in the food industry remain one of the most relevant directions of scientific and technological research today. This study focuses on the methods for obtaining biocatalysts, their properties, and their application in industrial processes.

METHODS

The following methods were used in this study to obtain biocatalysts, evaluate their properties, and explore their potential applications in the food industry:

1. Extraction and Purification of Biocatalysts

To obtain biocatalysts, enzymes were extracted from natural sources such as microorganisms, plants, and animal cells. The extraction process involved the following technologies:

- Liquid-liquid extraction – Buffer solutions were used to extract enzymes from cells.
- Filtration and centrifugation – Enzymes were separated and purified from raw material residues.
- Chromatographic methods – Ion-exchange chromatography and gel filtration were applied for protein fractionation and purification.

2. Determination of Enzyme Activity

The activity of the obtained biocatalysts was assessed using the following analytical methods:

- Spectrophotometric analysis – UV-Vis spectrophotometry was used to determine enzyme-substrate interactions.
- pH and temperature sensitivity test – The optimal working conditions of the enzymes were identified.
- Substrate specificity and kinetics – The Michaelis-Menten kinetics model was applied to study the substrate binding characteristics of the enzymes.

3. Enzyme Immobilization

To enhance the stability and long-term usability of enzymes, immobilization technologies were applied:

- Adsorption method – Enzymes were bound to solid surfaces.
- Covalent bonding – Enzymes were strongly attached to inert carriers.
- Encapsulation – Enzymes were protected by embedding them in polymeric capsules.

4. Investigation of Applications in the Food Industry

To determine the efficiency of biocatalysts in the food industry, experimental studies were conducted in the following areas:

- Bakery industry – The impact of enzymatic treatment on dough structure and softness was evaluated.
- Dairy industry – The effect of lactase on lactose breakdown was analyzed.
- Meat products – The influence of proteases on meat tenderness and organoleptic properties was studied.
- Beverage production – The role of pectinases in juice clarification was examined.

The research findings were processed through statistical analysis to evaluate the efficiency of biocatalysts and their advantages in technological processes.

RESULTS AND DISCUSSION

1. Extraction and Purification of Biocatalysts

Various methods were tested for extracting biocatalysts, and their efficiency was evaluated. The overall yield and purity of the obtained enzymes are presented in the following table:

Table 1. Efficiency of Biocatalyst Extraction and Purification

Extraction Method	Enzyme Type	Yield (%)	Purity Level (Moderate/High)
Liquid-liquid extraction	Amylase (<i>Bacillus subtilis</i>)	72%	Moderate
Filtration + centrifugation	Protease (<i>Aspergillus niger</i>)	80%	High
Ion-exchange chromatography	Lactase (<i>Kluyveromyces lactis</i>)	90%	Very High
Heterofiltration	Pectinase (<i>Aspergillus spp.</i>)	85%	High

These results indicate that **chromatographic methods** provide the highest purity levels for enzyme extraction. Notably, **ion-exchange chromatography** achieved the best results, offering the highest yield and purity.

2. Determination of Enzyme Activity

The optimal activity of biocatalysts was assessed under different temperature and pH conditions. The results are summarized in the following table:

Table 2. Enzyme Activity Depending on Temperature and pH

№	Enzyme Type	Optimal Temperature (°C)	Optimal pH	Maximum Activity (%)
1	Amylase	45°C	6.5	92%
2	Protease	50°C	7.0	95%
3	Lactase	37°C	6.0	88%
4	Pectinase	40°C	5.5	90%

These results demonstrate that each enzyme reaches its highest activity under specific optimal conditions. For instance, **amylase functions most efficiently at 45°C**, while **protease shows peak activity at 50°C**. Understanding these optimal conditions is crucial for maximizing enzyme performance in industrial applications.

3. Enzyme Immobilization

Enzyme immobilization enhances stability and prolongs their usability. The efficiency of different immobilization methods is presented in the following table:

Table 3. Enzyme Activity After Immobilization

Enzyme Type	Immobilization Method	Activity Retention (%)	Stability (Days)
Amylase	Adsorption	80%	25
Protease	Covalent bonding	90%	40
Lactase	Encapsulation	85%	35
Pectinase	Adsorption	78%	20

Among the tested methods, covalent bonding demonstrated the highest efficiency, as proteases retained 90% activity and remained stable for 40 days after immobilization. Encapsulation also provided strong stability, particularly beneficial for applications in dairy and beverage industries.

4. Application in the Food Industry

The impact of enzymes on food products was evaluated, and the results are presented in the following table:

Table 4. Improvement of Food Products Using Enzymes

№	Food Sector	Enzyme Type	Efficiency Indicator	Change (%)
1	Bakery	Amylase	Increase in bread volume	+20%
2	Dairy	Lactase	Breakdown of lactose	+95%
3	Meat	Protease	Meat tenderness	+30%
4	Beverages	Pectinase	Juice clarity improvement	+40%

These findings confirm that enzymes play a crucial role in enhancing food quality and processing efficiency. For instance, amylase improves bread volume by 20%, making baked products lighter and fluffier. Lactase breaks down 95% of lactose, making dairy products suitable for lactose-intolerant individuals. Protease improves meat tenderness by 30%, enhancing texture and quality, while pectinase increases juice clarity by 40%, leading to more visually appealing and refined beverages.

Overall, these results highlight the industrial potential of biocatalysts in optimizing food production processes, improving product quality, and increasing efficiency in various sectors of the food industry.

DISCUSSION

The results of this study provide significant insights into the extraction, activity analysis, immobilization, and application of biocatalysts in the food industry. Various methods were tested for the extraction of biocatalysts, and their effectiveness was compared. Specifically, ion-exchange chromatography and heterofiltration were identified as the most efficient techniques for obtaining highly purified enzymes. Liquid-liquid extraction was used for extracting enzymes from cells; however, it proved challenging to completely remove impurities. Filtration and centrifugation played a crucial role in the initial purification steps, effectively separating enzymes from raw material residues. Additionally, maintaining appropriate temperature and pH conditions during enzyme extraction was observed to be critical for preserving enzymatic activity. The findings indicate that optimizing the extraction conditions helps extend the functional lifespan of enzymes.

Enzyme activity was assessed using spectrophotometric analysis, pH and temperature sensitivity testing, and studies on substrate specificity and kinetics. Spectrophotometric analysis provided precise data on enzyme-substrate interactions. The results showed that the optimal temperature for most enzymes ranged between 35-45°C, with the highest activity observed within this range. The pH stability tests indicated that enzymes retained their highest stability within the pH range of 5.5-7.5, confirming their suitability for food processing applications. Kinetic studies based on Michaelis-Menten kinetics helped determine substrate binding properties. The analysis revealed that some enzymes exhibited high substrate specificity, making them particularly promising for specific biotechnological applications.

Enzyme immobilization techniques were investigated to enhance enzyme stability and prolong their usability. The results demonstrated that although the adsorption method was simple and cost-effective, it did not provide sufficient stability for long-term enzyme activity. The covalent bonding method significantly improved enzyme reusability by firmly attaching them to inert carriers. This technique allowed enzymes to be used multiple times, which is a crucial factor in industrial applications. The encapsulation method proved to be highly effective in protecting enzymes and increasing their stability. Encapsulating enzymes within polymeric capsules shielded them from environmental influences, ensuring long-term storage and extended usability. The findings indicate that immobilized enzymes outperform free enzymes in terms of longevity and reusability, making them highly advantageous for food industry applications.

The investigation of biocatalyst applications in the food industry provided valuable insights into their impact on various products. In the baking industry, enzymes were used to improve the physicochemical properties of dough, enhancing its rising ability and softness. The results showed that enzymatic treatment significantly improved the quality and organoleptic properties of baked goods. In the dairy industry, the effect of lactase on lactose breakdown was studied. Experimental results demonstrated that lactase effectively reduced lactose content in dairy products, which is particularly beneficial for lactose-intolerant consumers. In meat processing, the impact of proteases on meat tenderness and organoleptic properties was evaluated. It was observed that protease-treated meat exhibited improved tenderness and enhanced flavor. In beverage production, the role of pectinases in juice clarification was analyzed. The results showed that pectinases significantly increased juice clarity, making the final product more visually appealing and commercially viable.

Conclusion

This study investigated the extraction, purification, activity analysis, immobilization, and industrial applications of biocatalysts in the food industry. The findings demonstrated that ion-exchange chromatography and heterofiltration were the most effective methods for obtaining highly purified enzymes. Enzyme activity assessments revealed optimal temperature and pH conditions, confirming their suitability for food processing. Immobilization techniques, particularly covalent bonding and encapsulation, significantly enhanced enzyme stability and reusability. The application of biocatalysts in the food industry proved beneficial, improving the quality of bakery products, enhancing lactose hydrolysis in dairy, increasing meat tenderness, and optimizing juice clarification. These results

underscore the potential of biocatalysts as sustainable and efficient alternatives to conventional processing methods, offering advantages in product quality, environmental sustainability, and industrial efficiency. Further research is recommended to refine enzyme production and explore novel biotechnological applications.

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