



The Development and the Application of the Microbial Enzymes

--Take the Polar Microbial Enzymes as an Example

Jiaxuan Yang

Greentown Ivy Academy, Hangzhou, China

13066623703@163.com

ABSTRACT

This article systematically explores the development history, current application status and future prospects of microbial enzymes, with a particular focus on the unique structure and function of polar microbial enzymes. The aim is to break through the technical bottlenecks of traditional enzyme preparations and explore their innovative application potential in the industrial field.

KEYWORDS

Microbial Enzymes, Application, Future Prospects, Polar Microbial Enzymes, Function, Traditional Enzyme Preparations, Industrial Field, Innovation.

1. INTRODUCTION:

Microbial enzymes, as biocatalysts, speed up chemical reactions. Compared to traditional chemical processes, they offer numerous advantages in terms of sustainability and process efficiency. They enjoy widespread popularity in diverse global markets due to their ability to effortlessly address various needs and reduce production costs for companies. However, the application of microbial enzymes in production processes still needs to address some essential technical and practical issues, such as enzyme stability, activity in non-biological conditions, and cost-effectiveness in industrial-scale applications. In recent years, the polar microbe enzymes that have been constantly discovered seem to have a high possibility of addressing some of these problems. This article provides an overview of the development, current applications, and future prospects of microbial enzymes, particularly those from polar regions.

1.1. introduction of microbial enzymes

Enzymes are basically proteins or RNA produced by living cells, which have high specificity and highly efficient catalytic abilities for their specific substrates.

Microbial enzymes, a type of protein produced by microbial cells, are specialized catalysts that can accelerate specific chemical reactions within biological systems, exhibiting high efficiency and specificity. The catalytic mechanism of microbial enzymes is based on their different active sites, this specific tertiary structure of proteins enables them to recognize and bind with specific substrate molecules. The active site of an enzyme, comprising a sequence of amino acids, accelerates reaction rates by significantly reducing the activation energy required for the chemical process. Simultaneously, microbial enzymes can also be involved in various chemical conversion activities



during the microbial metabolism process, including energy generation, substance synthesis, and hydrolysis. In natural environments and within the human body, microbial enzymes also play an important role in complex ecological interactions, influencing the ecological balance in nature and human health.

1.2. the development of the microbial enzymes

Enzymes were first discovered during the process of brewing wine, with a notable mention of their discovery by Helment in 1684.. However, over a long time after that, no scientist made any further understanding or exploration of enzymes. By 1894, Fischer had proposed the first mechanism of enzyme action and derived a foundational theory -- the lock and key model, which describes the specificity of enzymes in a manner analogous to how a key operates a lock, with each enzyme fitting only one specific substrate. the specificity of the enzymes. Then, in 1959, Koshland further developed a more precise model -- induced fit model, providing a basis for the application of microbial enzymes. Before the 1950s, the enzyme preparation industry grew slowly due to the poor technologies. Until the 1960s the progress of fermentation technology for antibiotics and the improvements in strain breeding technology drove the rapid development of the microbial enzyme preparation industry. With the discovery of more and more enzymes, they have been widely incorporated into various industries and have gradually gained recognition among people.

1.3. The application fields of microbial enzymes

The "Kyoto Encyclopedia of Genes and Genomes" by Minoru Kanehisa revealed that a total of 6,904 proteins were involved in 320 KEGG pathways, among which 32% were enzyme protease, accounting for 2258. Genetic mutations that lead to enzyme deficiency or denaturation can result in numerous serious diseases. Therefore, the study of the mechanism of enzyme action can help people understand the pathogenesis of diseases and subsequently apply beneficial enzymes in treatment programs.

Another important application of enzymes is in the synthesis of pharmaceuticals. Enzymes not only decrease the occurrence of side reactions that produce undesired products, but also enhance the purity of the final product. In the agricultural aspect, microorganisms and their metabolic products that contain enzymes can improve soil conditions and increase crop yields. Specifically, microbial enzymes can effectively break down organic phosphorus and other pesticide residues in the soil. Most of these pesticides are non-biodegradable under natural conditions and the long-term accumulation of these toxins can have serious impacts on the environment and human health. However, phosphatase can efficiently decompose these pesticides and reduce soil pollution. The application of enzymes has diversified the food industry, significantly enhanced the nutritional components in food, and greatly improved the taste of food. Meanwhile, microbial enzymes have gradually been applied in food safety testing and achieved good application results, like ELISA and biosensors.

1.4. The introduction of polar microbial enzymes

Polar regions have distinct geographical, climatic, and environmental characteristics, including low temperatures, nutrient deficiencies, extreme pH levels, high salinity, and harsh light conditions. Microorganisms in these polar environments have adapted to such conditions by evolving a range of structures and functions. Consequently, the microbial enzymes produced by these organisms -- such as cold-adapted enzymes -- are capable of efficiently catalyzing reactions at low temperatures. This adaptation enhances their potential to overcome the limitations associated with normal enzymes, like the needs of precise and optimum temperatures.

1.5. The research purposes

Microbial enzymes are recognized as highly efficient biocatalysts and have been widely applied in various fields. However, in recent years, their inherent limitations have led to certain bottlenecks in the development and utilization. Nevertheless, the research and development of extreme enzymes, especially those from polar extremophiles, are likely to be the key to overcoming these research bottlenecks. This study introduces the unique structure and function of polar microbial enzymes and reviews their applications and development in various fields, aiming to explore the possibility of their application in other new fields in the future.

2. BASIC INFORMATION IN POLAR REGIONS

On our planet, there are two polar regions, the Arctic and the Antarctic. These areas are extremely cold and mostly covered with ice and snow, with temperatures often dropping below zero degrees Celsius.

1. Muhammad Asyraf Abd Latip (2019) stated in *Microbial Hydrolytic Enzymes: In Silico Studies Between Polar and Tropical Regions*: "The lowest temperature recorded in the Arctic region is -68°C, while the global lowest temperature was documented on the East Antarctic Plateau at -87.2°C. The Antarctic continent has an annual average temperature of -30°C." [1]

Although these extremely cold regions appear uninhabitable for humans, they host numerous other life forms, particularly microorganisms. In addition to cold-adapted species like polar bears and penguins, microorganisms have also successfully colonized these areas.

2. In the field of microbiology, bacterial populations in polar regions are a key research focus. Many microbiologists have discovered a rich variety of bacterial species in the seawater, sediments, and snow layers of these cold areas. Research shows that these bacteria have fully adapted to their surrounding environment through genetic evolution. Enzymes extracted from psychrophilic microorganisms are called cold-active enzymes or cold-adapted enzymes, which possess unique characteristics. Compared with traditional enzymes, many researchers are highly interested in exploring the advantages and potential value of these cold-active enzymes. These enzymes exhibit lower activation energy, which can reduce energy consumption and production costs. Additionally, when operated at low temperatures, they can be precisely activated, avoiding corruption or damage, and reducing bacterial or fungal contamination.
3. In recent years, the exploration of the diversity of polar microorganisms and the research on their active secretion have become the cutting-edge and hot topics in the field of international microbiology, among which the development and utilization of enzyme resources have attracted particular attention. Wang Wei mentioned in "Research Progress on the Development of Polar Microbial Enzyme Resources" (2020) that:

The research on enzymes from polar microorganisms began in the 1990s. Initially, the focus was on enzymes such as proteases, lipases, and amylases that have significant industrial application value. The extreme enzymes secreted by polar microorganisms, such as cold-active enzymes and salt-tolerant enzymes, exhibit unique biological characteristics:

- 1) Low-temperature enzymes can still maintain high catalytic activity under low-temperature conditions. The optimized design of the active sites in their molecular structures enables them to maintain dynamic conformations in low-temperature environments.
- 2) Salt-tolerant enzymes achieve structural stability and functional persistence in high-salt environments through special ion-binding sites and charge distributions. [2]
4. Stefano Bruno mentioned in "Enzymes from Marine Polar Regions and Their Biotechnological Applications" in 2019 that enzymes are classified into six main classes according to the type of

catalyzed reaction, namely oxidoreductases, transferases, hydrolases, lyases, isomerases and ligases. For instance, among the discovered carbohydrases, galactosidase can be used as a candidate substance to remove lactose from dairy products at low temperatures. Amylase, due to its stain-removing effect, can be used as a detergent additive in cold water washing, wastewater treatment, bioremediation in cold climates, and molecular biology applications, and also has great potential in the food industry. In addition, xylanase is also actively used in the textile industry. Just with one type of carbohydrase from polar microorganisms, it has demonstrated diverse applications and contributions in multiple fields, which indicates that the field of polar microorganism enzymes holds great potential in the future.[3]

These polar enzymes with unique structures and functions not only break through the application temperature and salinity limitations of traditional enzyme preparations, expanding the application scope of microbial enzymes in special fields such as low-temperature food processing and bioremediation in high-salt environments, but also provide new ideas for the directed modification and innovative design of enzyme engineering from the molecular mechanism level, promoting the advancement of enzymology research towards the frontier field of "analyzing extreme adaptability".

3. APPLICATION OF POLAR MICROBIAL ENZYMES

3.1. The application of microbial enzymes in the laundry industry

Currently, microbial enzyme compound preparations have been widely used in the laundry industry, mainly due to their excellent cleaning performance, environmental advantages, and economic value. Firstly, enzymes exhibit strong stain decomposition capabilities. Different types of microbial enzyme preparations can effectively target protein stains such as blood and milk, as well as stubborn stains like grease, juice, and coffee. Through precise catalytic action, they break down these stains into small molecules, significantly enhancing the cleaning effect. Proteases can recognize specific peptide bonds in protein molecules and hydrolyze them, breaking down large protein molecules into smaller peptides and amino acids. Lipases can hydrolyze fat molecules into fatty acids and glycerol. Amylases can hydrolyze the α -1,4-glycosidic bonds in starch molecules, breaking down starch into smaller sugars such as maltose and glucose. These small sugars have good solubility in water and are easily washed away. Cellulases can hydrolyze the β -1,4-glycosidic bonds in cellulose molecules, removing microfibers and fuzz from the fabric surface that accumulate during washing and wearing, making the fabric surface smoother. They also help remove dirt adhering to these microfibers, improving the appearance and feel of the fabric. Secondly, microbial enzymes are environmentally friendly. During the washing process, they can fully breakdown stains, reducing the use of chemical detergents and lowering water pollution. Additionally, the environmental load during the production and use of enzyme preparations is relatively low, aligning with the concept of green development. Microbial enzymes have significant advantages in terms of economy and energy conservation. Although they account for a small proportion of the cost of detergents, they can significantly improve washing efficiency, allowing clothes to be cleaned at low temperatures and with low water consumption. This not only saves water and electricity but also shortens the washing time and protects the color and texture of the clothes, extending their lifespan. Therefore, microbial enzymes, with their multiple advantages of high efficiency, environmental friendliness, and energy conservation, have become the ideal choice for the laundry industry.

Different types of enzymes have their own suitable pH values, temperatures, and ion concentrations. When multiple enzymes are used together, some enzymes may become inactive due to environmental conditions deviating from their optimal range or be interfered with by the activities of other enzymes, leading to a decrease in overall activity and stability. In daily laundry, to ensure the efficacy of compound enzyme detergents, it is necessary to strictly control conditions such as washing temperature, which not only increases operational complexity but also raises costs during production

and use. At this point, the emergence of polar microbial enzymes holds promise as a breakthrough to this limitation.

Stefano Bruno pointed out [3] that microbial enzymes such as α -amylase, serine protease, lipase, esterase, α -glucosidase, and cellulase that occur in polar regions, due to the similar living environments of the organisms that produce them, tend to have similar optimal pH and temperature values. When applied in complex microbial enzyme preparations, under most environmental conditions, they can fully exert their catalytic activity thanks to their strong environmental adaptability. This not only significantly enhances the efficiency of stain decomposition by detergents but also simplifies the exploration of suitable conditions for different enzymes during the research and development process, greatly shortening the R&D cycle and reducing costs, demonstrating extremely high application value.

3.2. The application of microbial enzymes in the food industry

3.2.1. Fruit and vegetable processing

Juice processing is the core link in fruit and vegetable processing. During the juice extraction process, pectin substances released from the intercellular spaces of plants, due to their high viscosity, can seriously affect the filtration and clarification of the juice. The application of microbial enzyme technology can effectively decompose the pectin in the juice, reduce viscosity, and significantly increase the yield and clarity of the juice. [4]

Take the production of orange juice as an example. The traditional process uses acidic and alkali methods to remove the peel, which generates a large amount of waste, pollutes the environment, and affects the quality of orange juice. The application of biotechnology, by utilizing the synergistic effect of various enzymes such as hemicellulase and pectinase, can efficiently remove the peel, overcome the drawbacks of traditional methods, achieve green production, and provide a more environmentally friendly and efficient technical solution for the fruit and vegetable processing industry.

3.2.2. Grain feeding

Grains are rich in starch and have high nutritional value. By applying microbial enzyme technology specifically, the starch in grains can be deeply processed and widely used in fields such as alcohol and sugar production. With the vigorous development of contemporary medicine and nutrition, based on the nutritional characteristics of grains and combined with microbial enzyme technology, it is possible to scientifically formulate grain foods that meet human nutritional needs. For instance, dietary fiber, a key component of food nutrition, is composed of various fiber substances and is of great significance in optimizing human physiological functions. During the processing of grains, with the aid of microbial enzyme technology, long-chain and high-molecular-mass starch can be transformed. By shortening the molecular chains and reducing the molecular mass, it can be converted into dietary fiber, providing a new approach for upgrading food nutrition and creating more possibilities for the development of healthy foods.[5]

3.2.3. Dairy products

The dairy industry spans both the food industry and animal husbandry, making it a highly promising cross-industry sector. Take the production of dry cheese as an example. The traditional process relies on chymosin extracted from the abomasum of calves. However, the natural supply of chymosin is scarce and far from meeting the large-scale demands of the food processing industry. To address this contradiction, the research and application of artificial bovine milk enzymes have emerged, significantly enhancing the production efficiency of dry cheese and effectively alleviating the imbalance between supply and demand, thereby promoting the growth of industry economic benefits. Infant formula milk powder, as a key category in the dairy industry, has higher requirements for microbial enzyme technology. Due to the difference in fatty acid composition between cow's milk fat and human milk, it is difficult to fully meet the nutritional needs of infants. Through microbial enzyme

technology, researchers have successfully developed human milk fat substitutes and added them to infant formula milk powder, greatly increasing the nutritional similarity between the formula and human milk, providing infants with better and more tailored nutritional support, and becoming an important achievement in technological innovation in the dairy industry.[6]

3.2.4. Restriction

Among these technologies, the high specificity of microbial enzymes is both an advantage and a limitation in application. As a single enzyme can only catalyze a specific type of chemical reaction, and food components are complex and diverse, the processing often involves multiple steps of reactions. Take the processing of grains as an example. It is necessary to use amylase to break down starch and protease to treat proteins. The need for multiple enzymes to work together makes the process more complicated and significantly increases production costs. In addition, microbial enzymes are extremely sensitive to environmental conditions. Even slight changes in temperature, pH value, and heavy metal ions can lead to a decrease in enzyme activity or even inactivation. In food processing, to extend the shelf life and inhibit bacterial growth, some production steps need to be carried out at low temperatures. However, low temperatures can reduce the activity of enzyme proteins, making it difficult for them to perform their catalytic functions. Under extreme pH conditions, the specific structure of enzymes is disrupted, and their activity also drops significantly. These characteristics impose extremely high requirements on the control of process conditions in food processing. Enterprises need to invest more resources to optimize and monitor the production environment, further increasing the difficulty and cost pressure of production.

3.2.5. Breakthrough

The enzymes of polar microorganisms, such as aminopeptidase, β -galactosidase, xylanase, and polygalacturonase, which have been discovered, can act simultaneously on different organic groups, bringing innovation to food processing. For instance, in cheese production, the combined application of the enzyme complex esterase and β -galactosidase is highly representative. These two enzymes can maintain high activity under the same temperature and pH conditions. The β -galactosidase enzyme focuses on decomposing the proteins in milk to form curd, while esterase efficiently hydrolyzes fats to improve flavor. Both enzymes work simultaneously, significantly shortening the fermentation and ripening cycle of cheese. This synergistic catalytic mode not only increases production efficiency by nearly 30%, but also reduces the equipment investment and energy consumption required for staged processing, lowering the overall production cost by approximately 20%, bringing significant economic benefits and technological breakthroughs to the dairy industry.

3.3. In the field of pharmaceuticals

3.3.1. Synthetic Drugs

In the synthesis of the anti-cancer drug paclitaxel, specific oxidases play a crucial role. By selectively oxidizing the precursor molecules of paclitaxel with oxidases, precise and specific modifications to the D-ring of paclitaxel can be achieved. Experimental data shows that when microbial enzymes are used to treat the paclitaxel precursors, the conversion rate can reach 95%, and the optical purity of the obtained product exceeds 99%. [7] This technology not only significantly improves the economic efficiency of drug synthesis but also reduces environmental pollution by eliminating the use of highly toxic chemical reagents. In the research and production of anti-diabetic drugs, microbial enzymes also demonstrate unique advantages. Researchers use specific transferases to transfer functional groups to target molecules with a conversion rate of over 90%, successfully synthesizing key intermediates. To ensure the activity and stability of the enzymes, the reaction must be strictly controlled within a temperature range of 30-35°C and a pH value of around 7.5, which not only protects heat-sensitive substrates but also ensures the efficient progress of the reaction. Compared with traditional chemical synthesis methods, microbial enzyme technology not only significantly improves reaction selectivity and reduces the occurrence of side reactions but also produces higher

purity final products, opening up a new path of green and efficient synthesis in the field of pharmaceuticals.

3.3.2. Pharmacokinetics

Polar microbial enzymes have demonstrated irreplaceable superiority. For instance, psychrophilic β -galactosidase can maintain over 90% activity at 4°C, a characteristic that enables it to continuously catalyze the generation of drug metabolites in low-temperature bioreactors, avoiding the significant drop in activity of conventional enzymes during refrigerated storage, which leads to deviations in metabolic simulation. In the synthesis of the anticoagulant drug heparin, sulfatase isolated from Arctic marine sediments has an optimal reaction temperature (15-20°C) that perfectly matches the storage conditions of the drug's active ingredients. This not only boosts the enzyme's catalytic efficiency by 40%, but also reduces the degradation rate of heat-sensitive components from 12% in traditional processes to less than 3%. The structural adaptability at the molecular level is the core of the breakthrough advantages of polar enzymes.[2]

3.3.3. Production constraints

The commercial production of microbial enzymes is highly dependent on fermentation technology, which requires precise control of cultivation conditions such as temperature, pH, and dissolved oxygen to optimize microbial growth and increase enzyme yield. However, this process faces multiple cost and technical challenges: on the one hand, the cost of raw materials for the culture medium remains high, and when specific growth promoters are added or high-value carbon sources such as glucose or glycerol are used, production costs increase significantly. On the other hand, the process of extracting enzyme activity is complex, involving multiple rounds of centrifugation, filtration, and chromatographic separation, each step of which may cause loss of enzyme activity, directly affecting the final yield. Moreover, in continuous fermentation, any temperature fluctuation or pH deviation during the extraction and purification stages can easily lead to a decrease in enzyme activity, posing a severe challenge to the control of product yield and quality.

3.3.4. The advantages of polar microbial enzymes

Polar microbial enzymes, due to their unique resistance to extreme environments, have shown great application potential in industrial production. Moreover, polar microbial enzymes can maintain high activity and stability under mild conditions, such as efficiently catalyzing reactions in low-temperature environments. This eliminates the need for expensive specially designed high-temperature and corrosion-resistant equipment in the production process, reduces energy consumption, and significantly lowers equipment procurement, maintenance costs, and production energy consumption. It is estimated that after introducing polar microbial enzyme technology, the equipment investment cost in some food and chemical production processes can be reduced by more than 30%, and energy consumption costs can be reduced by about 20%, bringing significant economic benefits to enterprises and promoting the development of green and low-carbon production models.

4. THE FUTURE DEVELOPMENT AND PROSPECT OF POLAR MICROBIAL ENZYMES

4.1. In the field of pharmacy

It has been discovered through cryo-electron microscopy that the lipase derived from *Pseudomonas antarctica* possesses a unique α -helix flexible domain, which acts as a "molecular spring" design. This enables it to maintain a stable conformation within a wide temperature range of -20°C to 35°C. Compared to mesophilic enzymes with an optimal temperature window of 5-10°C, the application scenarios have expanded by 6-8 times. More notably, the surface charge distribution of polar enzymes exhibits distinctive polarized characteristics. For instance, the laccase produced by bacteria from the

Greenland ice sheet has 23% more positively charged lysine residues on its surface than conventional enzymes. This feature significantly enhances the binding efficiency of the enzyme with negatively charged drug molecules such as heparin and hyaluronic acid, demonstrating breakthrough loading capacity in the construction of targeted drug carriers. These breakthroughs are reshaping the technological landscape of the pharmaceutical industry. The Norwegian biotechnology company ArcticZymes has successfully developed a novel DNA ligase using polar microbial enzymes, enabling room-temperature ligation reactions in the production of PCR diagnostic reagents. This reduces the energy consumption of the traditional step requiring 65°C high-temperature treatment by 80%.[8] Even more exciting is that the psychrophilic proteases isolated from permafrost have been applied in the biocatalytic synthesis of hydrophobic anticancer drugs such as paclitaxel due to their activity in organic solvents. This has simplified the multi-step chemical synthesis process into a single enzymatic reaction, and the raw material utilization rate has jumped from 48% to 92%. These cases confirm the key role of polar microbial enzymes in solving the "bottleneck" technical problems in drug production, and will also provide a new technological paradigm for building a green and efficient biopharmaceutical system in the future.

4.2. Cost Limitation Breakthrough

Driven by the vigorous development of biotechnology and genetic engineering, the application of microbial enzyme technology in the food industry has undergone significant changes. Among them, polar microbial enzymes have shown great application potential in food preservation due to their significant advantages such as being non-toxic and harmless, environmentally friendly, cold-resistant, highly specific in catalysis, not damaging food quality, and having high catalytic efficiency.

However, the current microbial enzyme technology faces a major bottleneck in practical application - the high price of enzyme products. This is mainly due to the high production cost of existing enzyme products, the difficulty in large-scale production, and the relatively limited market supply. The high price not only increases the production cost of food enterprises but also restricts the application and promotion of microbial enzyme technology in more scenarios, becoming an important factor hindering the rapid development of this technology. [3] Given the evidence that the total number of species in the ocean and the resulting biochemical diversity is likely higher than that on land, we have good reason to believe that in the near future, more natural products from cold environments will be applied in various biotechnology fields. Therefore, the development of a large number of yet-to-be fully explored polar microbial enzyme resources is of great significance. The unique ecological environment of the polar regions has nurtured a rich variety of microbial enzymes with unique properties, which may have better performance and lower production costs. Through in-depth research and development of polar microbial enzymes, it is expected to find new low-cost enzyme sources, improve production processes, achieve large-scale production, thereby effectively reducing the price of microbial enzyme products, breaking through the cost bottleneck of technological development, and promoting the wide application and rapid development of microbial enzyme technology in food preservation and other fields.

5. SUMMARY

Polar microorganisms, as a special group surviving in extremely cold environments, have developed unique physiological mechanisms and metabolic pathways through long-term evolution. They are an extremely important biological resource capable of producing enzymes with special properties. Compared with traditional microbial enzymes, polar microbial enzymes exhibit high activity at low temperatures. For instance, in the field of low-temperature detergents, traditional detergent enzymes have low activity at low temperatures, while polar microbial cold-active enzymes can significantly enhance the cleaning effect at low temperatures, reduce washing temperatures, and decrease energy consumption. In the food industry, they can be used for low-temperature processing and preservation,

avoiding the damage to food nutrition and flavor caused by high temperatures. In fruit and vegetable processing, they can improve texture and increase juice yield. In the feed industry, they can improve feed utilization and promote the effective absorption of various nutrients. In the dairy industry, they can solve problems such as insufficient supply of dairy products like milk powder and cheese, and improve product quality. In the field of synthetic drugs and drug metabolism, they provide new technical means for drug research and production, accelerating reaction processes and improving drug purity. With the deepening of research, polar microbial enzymes are expected to bring more innovative changes and development opportunities to various industries.

In the exploration journey of new biotechnological products, although the prospects are optimistic, the advancement of diversified strategies urgently requires sufficient resource empowerment and financial support from the academic system. The future industrial breakthrough path needs to build a collaborative innovation ecosystem between the academic and industrial sectors from the very beginning of research. As research deepens, on the one hand, the catalytic mechanism can be revealed by analyzing their molecular structure, providing a theoretical basis for enzyme engineering and improvement. On the other hand, their unique properties can be utilized to develop new enzyme resources, promoting development in multiple fields and playing a greater role in environmental protection, biopharmaceuticals, and other areas.

REFERENCE

- [1] Muhammad Asyraf Abd Latip, AAAH, NFHN. Microbial hydrolytic enzymes: In silico studies between polar and tropical regions. *Polar Science*. 2019. 06. DOI: 10.1016/j.polar.2019.04.003
- [2] Wang wei. A Review of Novel Polar Microbial Enzymes for Industrial Applications. *Chinese Journal of Polar Research*. 2020.06. DOI: 10.1378/j.jdyj.20190039
- [3] Stefano Bruno. Enzymes from Marine Polar Regions and Their Biotechnological Applications. *Marine drugs*. 2019. DOI: 10.3390/md17100544
- [4] Chen long. Application of Microbial Enzymes Technology in Food Processing and Preservation. *Food Science and Technology*. 2020.04. DOI: 10.16736/j.cnki.cn41-1434
- [5] Ching chunzhi. Application of Microbial Enzyme Technology in Food Processing and Testing. *Food Safety Journal*. 2018.05. DOI: 10.16043/j.cnki.cfs.2018.15.058
- [6] Yan xiaoyan. Application of Microbial Enzyme Technology in Food Processing and Detection. *Institute of Product Quality Supervision and Inspection of Tibet Autonomous Region*. 2022.06. DOI: 10.16043/j.cnki.cfs.2022.17.027
- [7] Wang huiming. The Application of Microbial Enzymes in Organic Processes. *Industrial Microbiology*. 2024.12. DOI: 10.3969/j.issn.1001-6678.2024.06.010
- [8] MAO Yang, Du Yixuan, Gao Xiangdong. Enzyme molecule modification and its application in medical field [J]. *The chemistry of life*, 2024, 44 (7) : 1240-1248. The DOI: 10.13488 / j.s MHX. 20240362.