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Exploration of the Role of Sulfur Bacteria in the Sulfur Cycle of Bottom Sediments in Aquaculture Ponds

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Abstract: As an important place for aquaculture, the water quality and ecological environment of aquaculture ponds are crucial for the growth and health of aquaculture organisms. The sulfur cycle, as an essential link in pond ecosystems, has a significant impact on water purification and the survival of aquaculture organisms. This article delves into the role of sulfur bacteria in the sulfur cycle in aquaculture ponds, including their promotion of sulfide oxidation, organic matter degradation, and provision of nutrients and energy for aquaculture organisms. Through comprehensive analysis, this article reveals the positive impact of sulfur bacteria on water purification in aquaculture ponds and the growth of aquaculture organisms, and proposes application strategies to optimize the living environment and increase the number of sulfur bacteria. This article also looks forward to the potential applications of sulfur bacteria in genetic manipulation, biological leaching, and environmental remediation, providing new ideas and methods for the ecological management of aquaculture ponds.

Keywords: Sulfur bacteria; Aquaculture pond; Sulfur cycle; Water purification

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1. Introduction

With the rapid development of aquaculture, water quality and ecological environment issues in aquaculture ponds are becoming increasingly prominent. Sulfides, as a common harmful substance in aquaculture ponds, pose a serious threat to the growth and health of aquaculture organisms. The sulfur cycle, as a key process in pond ecosystems, plays an important role in the transformation and removal of sulfides. As the main participants in the sulfur cycle, sulfur bacteria have gradually attracted the attention of researchers in terms of their physiological characteristics and ecological functions. By systematically analyzing the distribution characteristics, physiological mechanisms, and interactions with other microorganisms of sulfur bacteria in aquaculture ponds, this article will reveal the important role of sulfur bacteria in promoting water purification, improving the growth and health levels of aquaculture organisms, and other aspects. This article will also explore the practical application strategies of sulfur bacteria in the sulfur cycle of aquaculture ponds, as well as their potential application value in other fields, providing new perspectives and ideas for the research and application of sulfur bacteria.

2. Overview of sulfur bacteria

2.1. Classification and characteristics of sulfur bacteria

2.1.1. Survival environment and reproductive conditions

Sulfur bacteria live in diverse environments, ranging from deep-sea sediments to freshwater lakes, from hydrothermal vents to cold spring sediments. They are usually able to survive in extreme environments such as high salinity, high temperature, low oxygen, or anaerobic conditions. The reproductive conditions of sulfur bacteria also vary depending on their species, and they all require suitable pH values, temperature, light, and sufficient sulfides or other sulfur-containing compounds as energy and nutrients. In some cases, sulfur bacteria can also form symbiotic relationships with other microorganisms to jointly utilize resources in the environment [1].

2.1.2. Photosynthesis and energy acquisition

For sulfur bacteria capable of photosynthesis, photosynthesis is their main pathway for obtaining energy. These bacteria contain special photosynthetic pigments that can absorb light energy and convert it into chemical energy. During photosynthesis, sulfur bacteria use sulfides or thiosulfates as electron donors to convert light energy into energy substances such as ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide phosphate) through a series of enzymatic reactions. These energy substances are then used for bacterial growth, metabolism, and maintenance of their life activities. For sulfur bacteria that cannot carry out photosynthesis, they obtain energy through chemical processes, using sulfur-containing compounds such as sulfides as electron donors for respiration [2].

2.2. The importance of sulfur bacteria in the sulfur cycle

As a key microbial community in the sulfur cycle, sulfur bacteria play a crucial role by oxidizing sulfides, reducing sulfates, and decomposing organic sulfur. Firstly, sulfur bacteria can utilize sulfides as an energy source for growth and metabolic activities, during which sulfides are oxidized to sulfates or other sulfur-containing compounds. This process provides energy and nutrients for sulfur bacteria themselves, while also promoting the removal of sulfides and the generation of sulfates in the environment. Some sulfur bacteria can also reduce sulfates to sulfides, a process that occurs in marine sediments, freshwater lakes, and soil environments [3]. The reduction of sulfates provides electron acceptors and energy sources for sulfur bacteria and promotes the cycling and reuse of sulfates in the environment. Sulfur bacteria also participate in the decomposition and synthesis of organic sulfur. They can decompose organic sulfur compounds to release inorganic sulfur forms such as sulfides or sulfates and convert inorganic sulfur forms into organic sulfur forms and store them in living organisms [4].

3. Mechanism of sulfur cycling in bottom sediment of aquaculture ponds

3.1. Sources and forms of sulfur in sediment

The sulfur element in the sediment of aquaculture ponds mainly comes from two sources: natural sulfur sources and anthropogenic sulfur sources. Natural sulfur sources mainly include sulfur elements brought about by processes such as rock weathering, groundwater carrying, and atmospheric deposition. These sulfur elements exist in the sediment in inorganic sulfur forms (such as sulfides, sulfates, etc.) or organic sulfur forms (such as sulfur-containing organic compounds), while anthropogenic sulfur sources mainly include sulfur elements from sulfur-containing feed, drugs, and excrement from aquaculture organisms added during the breeding process [5].

The sulfur element in sediment exists in various forms, including inorganic sulfur (such as sulfides, sulfates, elemental sulfur, etc.) and organic sulfur (such as sulfur-containing amino acids, sulfur-containing proteins, etc.). These different forms of sulfur elements undergo a series of transformation processes in sediments, such as oxidation, reduction, methylation, and demethylation. These conversion processes are influenced by various factors, such as temperature, pH value, redox potential, and microbial activity [6]. Microbial activity is one of the key factors affecting the transformation

of sulfur forms in sediment. Sulfur bacteria, as an important microbial community in sediment, play a crucial role in the sulfur cycle by oxidizing sulfides, reducing sulfates, and decomposing organic sulfur [7].

3.2. The role of sulfur bacteria in sediment sulfur cycling

3.2.1. Oxidation of sulfides and formation of sulfates

(1) The process of sulfur bacteria oxidizing sulfides: Sulfur bacteria can use sulfides as an energy source for growth and metabolic activities. During this process, sulfides are oxidized to sulfates or other sulfur-containing compounds through a series of enzymatic reactions. This oxidation process usually occurs on the cell membrane or cytoplasm of sulfur bacteria, accompanied by electron transfer and energy release. The rate and efficiency of sulfide oxidation by sulfur bacteria are influenced by various factors, such as sulfide concentration, temperature, pH value, and redox potential [8].

(2) The impact of sulfate on pond ecology: Sulfate is one of the main products of sulfur bacteria oxidizing sulfides, and it plays multiple roles in aquaculture pond ecosystems. Firstly, sulfates can act as electron acceptors to participate in redox reactions in sediment, promoting the decomposition and mineralization of organic matter. Sulfate can also be absorbed and utilized as a nutrient by aquaculture organisms, promoting their growth and development. However, excessive sulfate concentration may also have adverse effects on aquaculture organisms, such as causing osmotic pressure imbalance and affecting metabolic processes [9].

3.2.2. Decomposition and conversion of organic sulfur

(1) Microbial decomposition pathways of organic sulfur: Organic sulfur is one of the important forms of sulfur in sediment, which includes complex organic compounds such as sulfur-containing amino acids, sulfur-containing proteins, and sulfur-containing polysaccharides [10]. These organic sulfur compounds undergo decomposition and transformation processes under the action of microorganisms, releasing inorganic sulfur forms such as sulfides or sulfates. Sulfur bacteria, as an important microbial community in sediment, can decompose various organic sulfur compounds and release inorganic sulfur forms [11].

(2) The role of sulfur bacteria in the process: Sulfur bacteria play a crucial role in the decomposition and conversion of organic sulfur. They can use their own enzyme system to decompose complex organic sulfur compounds and convert them into easily usable inorganic sulfur forms. This process provides energy and nutrients for sulfur bacteria, while also promoting the cycling and reuse of organic sulfur in sediment. Sulfur bacteria can also indirectly affect the decomposition rate and conversion direction of organic sulfur by regulating environmental factors such as redox potential and pH value in sediment, affecting the activity of other microorganisms [12].

3.3. The interaction between sulfur bacteria and other microorganisms

There are complex interactions between sulfur bacteria and anaerobic bacteria in the sediment of aquaculture ponds. Sulfur bacteria and anaerobic bacteria compete for limited energy and nutrients, such as sulfides and organic matter, in sediment. This competitive relationship may lead to changes in the quantitative balance between the two, thereby affecting the sulfur cycling process in sediment. There may also be a symbiotic relationship between sulfur bacteria and anaerobic bacteria [13]. In some cases, anaerobic bacteria can use the sulfate produced by sulfur bacteria oxidizing sulfides as an electron acceptor for respiration, while sulfur bacteria can obtain energy and nutrients from the metabolic products of anaerobic bacteria [14].

As a vital microbial community in sediment, the presence and activity of sulfur bacteria have a significant impact on the microbial community structure of ponds. Firstly, sulfur bacteria alter the form and distribution of sulfur in sediment through processes such as oxidation of sulfides and decomposition of organic sulfur, thereby affecting the survival and activity of other microorganisms. The activity of sulfur bacteria can also alter environmental factors such as redox potential and pH value in sediment, thereby affecting the activity of other microorganisms. Sulfur bacteria can also form complex interaction networks with other microorganisms, maintaining the stability and diversity of pond microbial communities

through competition, symbiosis, and predation [15].

4. The impact of sulfur bacteria on the environment of aquaculture ponds

4.1. Water quality regulation and purification function

In aquaculture ponds, nutrients such as phosphorus and nitrogen are essential for the growth of aquaculture organisms, but excessive concentrations can lead to water quality deterioration, causing problems such as the overgrowth of algae and eutrophication of water bodies [16]. Sulfur bacteria can convert nutrients such as phosphorus and nitrogen in water into other forms through a series of biochemical reactions, thereby reducing their concentration and mitigating their impact on water quality. For example, sulfur bacteria can use sulfides as electron donors to reduce nitrate to ammonia nitrogen or nitrogen, thereby reducing the nitrogen content in water. They can also remove phosphate and other phosphorus elements from water through adsorption, precipitation, and other processes [17].

The organic matter in aquaculture ponds mainly comes from the excrement, residual feed, and dead bodies of aquaculture organisms. These organic compounds decompose in water, producing a large amount of harmful substances such as ammonia nitrogen and sulfides, which seriously affect water quality and the health of aquaculture organisms. Sulfur bacteria play an important role in the degradation of organic matter. They can use their own enzyme system to decompose organic matter, converting it into inorganic or low-molecular-weight organic matter, thereby reducing the organic content in the water [18].

4.2. Promotion of the growth and health of aquatic organisms

During the process of oxidizing sulfides and decomposing organic matter, sulfur bacteria release some beneficial nutrients and energy for aquaculture organisms, such as their ability to oxidize sulfides into sulfates, providing sulfur elements for aquaculture organisms. They can also decompose organic matter and release nutrients such as ammonia nitrogen and phosphate, which can be absorbed and utilized by aquaculture organisms. Sulfur bacteria can provide nutrients and energy for aquaculture organisms and enhance their immunity by regulating the microbial community structure in water bodies. Research has shown that sulfur bacteria can inhibit the growth and reproduction of some pathogenic microorganisms, thereby reducing the incidence of diseases in aquaculture organisms [19].

4.3. Application strategy of sulfur bacteria in aquaculture ponds

To fully utilize the role of sulfur bacteria in aquaculture ponds, effective measures need to be taken to increase their population. On the one hand, adding sulfur-containing organic or inorganic substances to the pond can provide sufficient energy and nutrients for sulfur bacteria, promoting their growth and reproduction. On the other hand, bacterial strains can also be introduced from other sulfur-rich environments, such as deep-sea sediments, hydrothermal vents, etc., to enrich the sulfur bacterial community in aquaculture ponds. In addition to increasing the number of sulfur bacteria, it is also necessary to optimize their living environment to improve their activity and efficiency. It is important to reasonably control the water quality parameters of the pond, such as temperature, pH value, dissolved oxygen, etc., to maintain them within a suitable range for the growth and activity of sulfur bacteria. It is also necessary to strengthen the management and maintenance of ponds, regularly clean sediment, replace water bodies, etc., in order to reduce the accumulation of harmful substances and the inhibitory effect on sulfur bacteria [20].

5. Conclusion

This article comprehensively analyzed the role and impact of sulfur bacteria in the sulfur cycle of aquaculture ponds, revealing their important role in promoting water purification, improving the growth and health levels of aquaculture

organisms, and so on. By optimizing the living environment of sulfur bacteria and increasing their numbers, the ecological and economic benefits of aquaculture ponds can be further enhanced. The potential applications of sulfur bacteria in genetic manipulation, biological leaching, and environmental remediation also provide broad space for their future research and application. This study provides new ideas and methods for the ecological management of aquaculture ponds and opens up new directions for the research and application of sulfur bacteria.

Disclosure statement

The author declares no conflict of interest.

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