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The Latest Research Progress on Application of *Lactobacillus acidophilus*

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Abstract

Lactobacillus acidophilus belongs to the genus *Lactobacillus*, Gram-positive bacteria, which mainly colonize the small intestine of animals, can secrete anti-biotin substances, inhibit the growth and reproduction of some intestinal pathogenic bacteria, thereby regulating Intestinal flora, strengthen the absorption and utilization of feed nutrients, improve resistance, and promote animal growth, so it is widely used in livestock and poultry production. This article summarizes the latest research progress and application of *Lactobacillus acidophilus*, and looks forward to the future development direction in order to provide a theoretical basis for its future research.

Keywords

Lactobacillus acidophilus, Probiotics, Immune Function, Non-Antibiotic Culture, Microecological Preparation

1. Introduction

Currently, research has found that *Bacillus subtilis* can participate in intestinal activities as a very common probiotic [1], and it has various effects on gut microbiota. Firstly, in previous studies, it has been found that *Bacillus subtilis* can generate many antibacterial substances by itself, which have inhibitory effects on some pathogenic bacteria. For example, it can produce linoleic acid, which has a certain inhibitory effect on pathogenic bacteria in the intestine, such as *Salmonella*, *Escherichia coli*, etc. Secondly, other studies have found that *Bacillus subtilis* can regulate its microbial environment by secreting active substances, thereby regulating the gut microbiota balance of species [2]. It can promote the proliferation of beneficial bacteria such as lactic acid bacteria and bifidobacteria, thereby reducing the pH value of the intestine and enhancing its resistance to harmful bacteria. In addition, *Bacillus subtilis* can also promote the growth and repair of intestinal mucosal cells, and strengthen the intestinal barrier function [3]. It can increase the secretion of intestinal mucus and form a slime layer, so as to resist the invasion of harmful bacteria in the intestinal tract and protect the intestinal mucosa from damage. Related studies have found that *Bacillus subtilis* can survive for a period of time at higher temperatures and still have certain activity in acidic environments with pH < 7, without denaturation [4]. It is precisely because of these characteristics of *Bacillus subtilis* that it can maintain high activity in livestock and poultry production applications. Because *Bacillus subtilis* can make the nutrients in feed more easily absorbed by the intestinal tissue through its own decomposition, it also improves the absorption efficiency of animals for food conversion, improves the absorption of nutrients in animals, enhances their disease resistance and immune ability, and can improve the intestinal health of animals. It is precisely because *Bacillus subtilis* has a series of good effects on organisms that it has gradually been recognized by the public as one of the ideal probiotics to replace antibiotics in livestock and poultry breeding [5].

2. The Role and Mechanism of *Lactobacillus acidophilus*

Probiotics are a type of microbial flora that colonizes the body and is beneficial to the host. It has many important positive effects on the animal body, especially the intestinal probiotics, which can promote digestion and increase the absorption and utilization of nutrients. Improve the body's immunity, regulate the intestinal flora and improve intestinal health. Because probiotics can effectively promote feed utilization, promote the growth of livestock and poultry, strengthen animal body resistance, and prevent infectious diseases. Probiotics include *Actinomyces*, *Bifidobacterium*, *Lactobacillus* and *Bacillus*. *Lactobacillus acidophilus* is a type of probiotic bacteria that colonizes the gastrointestinal tract of animals. It mainly exists in the small intestine. It can produce and release lactic acid, acetic acid, and secrete a variety of anti-biotin substances, such as acidolin, Acidophilin, lactic acid bacteria, etc., which have antibacterial effects on pathogenic bacteria in the intestinal tract, reduce the production of various toxins, reduce the burden of liver detoxification, and are more conducive to the establishment of the host to its own Beneficial intestinal microflora [6]; In addition, through the secretion of lactic acid and acetic acid, *Lactobacillus acidophilus* can also enhance the body's ability to absorb and utilize calcium, phosphorus, iron and multiple vitamins; in addition, express specific structures The domain of recombinant oral *Lactobacillus acidophilus* can induce specific systemic and mucosal immune responses, improve the humoral and mucosal immunity of the animal body, thereby strengthening the body's immunity [7]. In summary, *Lactobacillus acidophilus* can regulate the intestinal flora, strengthen the absorption and utilization of feed nutrients, improve resistance, promote animal growth, and induce immunity.

3. The Latest Research Progress and Application of *Lactobacillus acidophilus*

3.1. Research and Application of *Lactobacillus acidophilus* in Livestock and Poultry Breeding

The eukaryotic expression recombinant plasmid carrying the S1 epitope of the Porcine Epidemic Diarrhea Virus (*PEDV*) S protein antigen site was transformed into *L. acidophilus*, and an oral vaccine was prepared. After oral immunization of mice, mice receiving recombinant *Lactobacillus acidophilus* produced higher levels of anti-PEDV-specific IgG and SIgA antibodies, and the level of cellular immune response was also significantly increased. In addition, oral immunization tests were performed on pregnant sows with *Lactobacillus acidophilus*, and the results showed that recombinant *Lactobacillus acidophilus* S1 could induce specific systemic and mucosal immune responses. In summary, oral immunization with *Lactobacillus acidophilus* can improve the humoral and mucosal immunity of sows, and is expected to be a candidate vaccine to prevent PEDV infection in piglets.

By using *Lactobacillus acidophilus* as a dietary additive to study the effects of *Lactobacillus acidophilus* on the growth performance, intestinal morphology, intestinal barrier function and immune response of broiler chickens challenged by *E. coli* O157, it is shown that *Lactobacillus acidophilus* can alleviate the pathological inflammation responds and regulates the expression of key immune molecules, enhances cellular and humoral immunity, improves intestinal barrier function, and enhances resistance, thereby resisting *E. coli* infection, improving broiler growth performance and intestinal health, and reducing mortality. Studies have shown that addiction *Lactobacillus* acidi is expected to be used as a dietary supplement as an intervention strategy for attenuating *E. coli* [8]. In the study of the effect of combining garlic extract preparation and *Lactobacillus acidophilus* into a synbiotic as a feed additive on broiler chickens, it was found that this kind of synbiotic can significantly improve the broiler's production performance, nutrient digestibility and intestinal health [9]. The compound probiotic tablets prepared by feeding mice with *Lactobacillus acidophilus* LA85 compressed tablets can help adjust the body's immune system, enhance the phagocytic function and NK cell activity, and enhance the body's immunity and safety Good [10]. In sea cucumber farming, the combined application of *Lactobacillus acidophilus* and Tussah Immune Active Substance (TIS) can significantly improve the immunity and feed digestibility of sea cucumbers, and improve the health of sea cucumbers intestinal tract [11].

In studying the impact of *Lactobacillus acidophilus* as an immune enhancer on the immunization process of Newcastle disease vaccine, it was found that oral *Lactobacillus acidophilus* can effectively increase the body's humoral immunity level, especially the level of IgG and HI-NDV antibodies. *Lactobacillus acidophilus* can be used as an immune enhancer to enhance the immunogenicity of the Newcastle disease vaccine [12].

3.2. Application and Research of *Bacillus subtilis* on Special Economic Animals (Mink)

In the balance of gut microbiota, beneficial bacteria can inhibit the growth of harmful bacteria and the production of potentially pathogenic bacteria, while promoting the metabolism and absorption of nutrients, thereby having a beneficial impact on host health. However, when the balance of gut microbiota is imbalanced, harmful bacteria may proliferate excessively, leading to the occurrence and exacerbation of intestinal diseases. Therefore, understanding and intervening in the composition and function of gut microbiota is of great value for maintaining host gut health and preventing related diseases. This experiment used 16s rRNA high-throughput molecular sequencing technology to determine and analyze the gut microbiota of minks fed with *Bacillus subtilis*.

According to existing research findings, the beneficial gut microbiota includes *Bifidobacterium* [13], *Lactobacillus*, *Lactobacillus acidophilus*, etc. *Bifidobacterium* can maintain intestinal microbiota balance, enhance immunity, promote calcium absorption, and prevent constipation and diarrhea [14]. After in-depth exploration and analysis of the experimental results, it was found that the use of *Bacillus subtilis* as a dietary feed did not significantly alter the species richness in the mink gut, but could alter the species composition of the mink gut microbiota. However, some studies have found that *Bacillus subtilis* increases species richness and evenness in the gut of silkworms [15]. It is speculated that this may be due to the different gut environments and species present in the gut of silkworms and minks. *Bacillus subtilis* plays a smaller role in the gut of minks than in the gut of silkworms.

Through ASV/OTU analysis, it was found that the experimental group had an increase in the number of bacterial colonies in the gut compared to the control group. This is consistent with the previous research showing that *Bacillus subtilis* can increase the number of soil microbial colonies [16]. Based on the results, it can be proven that there is an increase in certain beneficial bacteria or inhibition of the growth of certain harmful bacteria in the experimental group.

According to the Beta diversity analysis results, it was found that *Bacillus subtilis* can improve the richness and diversity of gut microbiota in minks, which is consistent with the previous research finding that *Bacillus subtilis* can increase soil species richness [17]. *Bacillus subtilis* can adjust the microbial colony structure, thereby increasing the proportion of beneficial bacteria in the intestine and reducing the proportion of harmful bacteria. In other words, *Bacillus subtilis* can regulate the relative number of gut microbiota and increase the proportion of certain beneficial bacteria, such as bifidobacteria and psychrophilic bacteria. At the same time, it can also reduce the proportion of some harmful bacteria, such as Enterococcus and *Escherichia coli*, so as to improve the balance of intestinal microecology. This effect can also extend to improving the immune system and health status of minks, promoting their growth and development.

As an aerobic bacterium, *Bacillus subtilis* can rapidly consume free oxygen in the intestine, forming an anaerobic environment, thereby promoting the formation of anaerobic bacteria in the gastrointestinal tract [18]. Additionally, *Bacillus subtilis* can produce active substances such as subtilisin, short peptide, and nystatin, which can inhibit the production of pathogenic bacteria [19]. So, after consuming feed mixed with *Bacillus subtilis*, the intestinal microbiota of minks significantly increased in Proteobacteria and decreased in Actinobacteria.

Some studies have found that certain proterozoic bacteria can participate in digestion and nutrient absorption processes, and can produce beneficial substances such as enzymes and short chain fatty acids [20], which play an important role in human health; Some members of the Firmicutes phylum can produce short chain fatty acids, which help promote intestinal health, reduce inflammation, and enhance immune system function [21]. At the same time, certain bacteria in the Firmicutes phylum can decompose difficult to digest food components such as cellulose, helping the body absorb nutrients; some strains of actinomycetes are related to obesity and metabolic diseases, and they are involved in regulating energy and glucose metabolism in the human body. The discovery of these research results has led to a significant regulatory effect of *Bacillus subtilis* in the gut microbiota of minks, playing the role of green probiotics.

The analysis of the results obtained at the genus level and on the species heat map found that compared with the control group, the test group significantly increased the genus of psychrophilic bacteria, and significantly reduced Enterococcus and Lactococcus. The results were consistent with the conclusions of the previous study that *Bacillus subtilis* played a beneficial role in inhibiting harmful bacteria in animals' intestines [22] and improving the intestinal flora of animals [23]. In addition, it is speculated that the proportion of psychrophilic bacteria in the experimental group has significantly increased, possibly due to the long-term consumption of cold and fresh food by minks, and the intervention of *Bacillus subtilis* has led to the enrichment of this bacteria genus.

3.3. The Immunomodulatory Effect of *Lactobacillus acidophilus*

After a meta-analysis of the data obtained from 2309 randomized controlled trials, it was concluded that *Lactobacillus acidophilus* can reduce the levels of tumor necrosis factor-α, IL-6 and a variety of pro-inflammatory cytokines. Tumor necrosis factor-α acts on vascular endothelial cells and damages endothelial cells, leading to vascular dysfunction, as well as vascular damage and thrombosis, leading to local blood flow obstruction of tumor tissue, as well as bleeding and hypoxic necrosis. IL-6 mainly stimulates the proliferation, differentiation and function of cells involved in the immune response. In the case of excessive secretion, pro-inflammatory cytokines act on the host defense mechanism, which may lead to immunopathological disorders. Therefore, by reducing the levels of tumor necrosis factor-α, IL-6 and other cytokines, *Lactobacillus acidophilus* can regulate the body's immunity [24]. In the study of the anti-cancer effect of *Lactobacillus acidophilus* CICC 6074 and its mechanism of action, it is concluded that *Lactobacillus acidophilus* CICC 6074 can activate the mitochondrial pathway and induce cell apoptosis to exert its anti-cancer effect [25].

3.4. Research on *Lactobacillus acidophilus* in the Field of Food Science and Engineering

In the research on the nutritional requirements of *Lactobacillus acidophilus* LA-5 and its application in fermented milk, aspartic acid, aspartic acid, cysteine, leucine, methionine, riboflavin, After guanine, uracil and Mn^{2+}, the milk fermentation time involved by *Lactobacillus acidophilus* LA-5 can be shortened by 9 h, and the number and vitality of *Lactobacillus acidophilus* have been significantly improved [26]. In the study of the effect of *Lactobacillus acidophilus* LA-05 fermented fruit puree (loofah, mango, mango and needles) on phenolic substances and antioxidant activity, it is shown that the Brazilian carcass fruit can be transformed by *Lactobacillus acidophilus* into Phenolic substances with antioxidant activity. Phenolic compounds are plant metabolites that can scavenge free radicals and regulate a variety of signal pathways, and play an important role in reducing the risk of chronic diseases. The conversion of phenolic compounds provides a theoretical basis [1].

In a frozen meat model system under vacuum and aerobic conditions, the effect of bioprotective extracts (BES) of *Lactobacillus acidophilus* on *Lactobacillus* putrefaction CRL1407 was evaluated at 4 and 10˚C. The results show that the BE-1 of *Lactobacillus acidophilus* has a complete inhibitory effect on *Lactobacillus* rot, and the antibacterial activity is mainly related to the production of extracellular polysaccharides and the effect of inhibitory treatment [27].

3.5. Research on the Technology of Microencapsulation of *Lactobacillus acidophilus*

In the study of the juice storage effect of *Lactobacillus acidophilus* LA-02 prepared by the complex coacervation-transglutaminase cross-linking method, it was found that compared with the direct addition of *Lactobacillus acidophilus*, it was added through microcapsules. *Lactobacillus acidophilus* can prolong its survival time. Microcapsules have a certain protective effect on *Lactobacillus acidophilus*, especially in orange juice. *Lactobacillus acidophilus* in the microcapsule group can survive for up to 63 days [28].

In the test, sodium alginate-whey protein is used as a composite wall material, and 4% lactulose, 8% skimmed milk, 1.5% sodium gibberellate, and 2% glycerol are added as a protective agent to prepare *Lactobacillus acidophilus* freeze-dried microcapsules. In the study of the survival rate of bacteria under the action of human gastric and intestinal juice, it was found that after the freeze-dried microcapsules were treated with artificial gastric juice for 150 minutes, the survival rate of the bacteria was 65.1%, and the survival rate of the non-freeze-dried microcapsules was 60.1%; in human intestinal juice Freeze-dried microcapsules need only 60 minutes to release completely, while non-freeze-dried microcapsules need 90 minutes to release completely; after storage at 4˚C for 60 days, the survival rate of *Lactobacillus acidophilus* freeze-dried microcapsules is 77.1%. The survival rate of dry microcapsules was 66.3%. It can be concluded that the addition of a suitable freeze-dried protective agent can improve the performance of *Lactobacillus acidophilus* microcapsules, and enhance the resistance of *Lactobacillus acidophilus* to stomach, intestinal juice and storage and other adverse environments *in vivo* and *in vitro* [29].

In a comparative study on the activity, stability and structure of *Lactobacillus acidophilus* LA-5 in microcapsules made of pectin and sodium alginate, it was found that sodium alginate and high methoxy pectin were used as carrier materials. The syringe emulsification method is used for microencapsulation. A higher encapsulation rate (>92%) was obtained. Compared with the addition in the free state, the microencapsulated *Lactobacillus acidophilus* had a higher survival rate and stronger activity, and the survival rate after reduction during storage was higher than 106 cfu/g, which proves that the microencapsulation process is feasible [30] [31].

4. Summary

As a probiotic, *Lactobacillus acidophilus* has a broad application space in the fields of livestock poultry breeding and mink breeding, medicine and food engineering. In the livestock and poultry breeding industry, currently *Lactobacillus acidophilus* can be used as an oral vaccine, dietary additive or adjuvant to enhance the resistance of livestock and poultry, improve feed digestibility and prevent infectious diseases. In the medical field, the latest research shows that *Lactobacillus acidophilus* can play an immunomodulatory role, and play an anti-tumor effect by reducing the levels of tumor necrosis factor and a variety of inflammatory cytokines. In the field of food engineering [32], *Lactobacillus acidophilus* can be used as a preservative for the preservative treatment of meat, fruits and juices. The research on the microencapsulation process of *Lactobacillus acidophilus* has also allowed *Lactobacillus acidophilus* to gain wider application space.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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