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REVIEW ARTICLE

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Application of *Weizmannia coagulans* in the medical and livestock industry

Linhao Wang†, Jie Wang†, Liyu Du†, Xiang Fang and Zhenlin Liao*

Abstract

Purpose: Products enriched with probiotics have always been fashionable. *Weizmannia coagulans* has become a hot research topic in the academic community due to their multiple functional properties and high resistance to stress, which can retain their activity in a variety of harsh environments. This review aims to evaluate the probiotic effects of different strains of *Weizmannia coagulans* in animals and humans and to inspire better exploitation of the value of this strain.

Methods: This review summarizes the latest research progress of *Weizmannia coagulans* from two major applications in animal breeding and human health.

Results: The functional properties of *Weizmannia coagulans* are extensively recognized. In animals, the strain can promote nutrient absorption, reduce mortality, and enhance the slaughter rate in livestock and poultry. In humans, the strain can be used to treat gastrointestinal disorders, immunomodulation, depressive symptoms, and non-alcoholic fatty liver. *Weizmannia coagulans* is projected as an ideal substitute for antibiotics and other chemical drugs.

Conclusion: Despite the outstanding functional properties of *Weizmannia coagulans*, there are numerous strains of *Weizmannia coagulans* and significant differences between strains in functional and physiological properties. Currently, there are few literature reports on the probiotic mechanism and functional gene identification of *Weizmannia coagulans*, which is crucial for the commercialization of *Weizmannia coagulans* and the benefit of human society.

Keywords: Probiotics, *Weizmannia coagulans*, Nutrient absorption, Mucosal immunity, Non-alcoholic fatty liver disease

Introduction

Weizmannia coagulans was formerly classified as *Bacillus coagulans*. In 2020, Canadian researchers conducted a more comprehensive genomic analysis of three hundred strains of *Bacillus* to elucidate the evolutionary relationships of *Bacillus*. It was discovered that most of the strains required to be reclassified except for *Bacillus subtilis* and *Bacillus cereus*. The original genus *Bacillus* should be divided into 17 new genera, and the original *Bacillus coagulans* belonging to the genus *Bacillus* was renamed *Weizmannia coagulans* (Gupta et al. 2020). However, considering the name is not generally familiar to the academic circle and most references are before 2020, the name, *Bacillus coagulans*, is still used in this paper as well as retains consistency with historical literature.

Bacillus coagulans is gram-positive, facultative anaerobic, non-toxic, rod-shaped, endospore-producing probiotic, which can decompose and utilize a variety of pentose and hexose and can produce lactic acid (Elshaghabee et al. 2017). It has a lot of features, for example, acid resistance, high-temperature resistance, high adhesion, scavenging free radicals, and so on (Sui et al. 2020; Kapse et al. 2018). The optimum growth temperature of

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the *Bacillus* ranges from 35 to 50 °C and the optimum growth pH ranges from 5.5 to 7.0. *Bacillus coagulans* has a strong tolerance to stomach acid, cholic acid, and other harsh environments so it has outstanding performance in the gastrointestinal model in vitro, with an average survival rate of 51% (Huang et al. 2021; Keller et al. 2019). In addition, thanks to high-temperature resistance, it has better processing performance and is implemented in more fields. In addition, the transport and storage conditions of *Bacillus coagulans* is comparatively loose, which is not available in conventional probiotics. Conventional probiotics, such as *Lactobacillus* and Yeast, are susceptible to adverse environmental conditions so they have to be processed at low temperatures for both transportation and storage (Shori 2016). Studies have certified that *Bacillus coagulans* has great potential for biological applications and have a wide range of applications in food, chemical, medical, etc. (Aulitto et al. 2022). Accordingly, *Bacillus coagulans* has become a research hotspot. The probiotic functions of *Bacillus coagulans* are shown in Table 1.

Besides, current research shows that *Bacillus coagulans* does not have any toxic side effects, confirming its safety (Kim et al. 2021; Saroj and Gupta 2020). *Bacillus coagulans* has long been reported as safe by the US Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA) and is on the Generally Recognized as Safe (GRAS) and Qualified Presumption of Safety (QPS) list (European Food Safety Authority Efsa 2013). In China, the Ministry of Health included *Bacillus coagulans* in the list of bacteria that can be used in food in 2016. At present, *Bacillus coagulans* is widely used in animal husbandry, medicine, and health fields (Fig. 1).

Table 1 The probiotic functions of *Bacillus coagulans*

Bacillus coagulans **strain**	**The probiotic function of the strain**	**References**
Bacillus coagulansTBC169	Improve intestinal morphology and increase body weight of broilers	Li et al. 2019
Bacillus coagulansATCC7050	Improve the growth and intestinal morphology of Penaeus and enhance the resistance to *Vibrio Parahaemolyticus*	Amoah et al. 2019
Bacillus coagulansATCC7050	Increase the number of intestinal *Lactobacillus* in broilers	Hung et al. 2012
Bacillus coagulansSCC-19	Reduce cadmium ion accumulation in liver and kidney of carp	Xing et al. 2018
Bacillus coagulansR11	Strong adsorption capacity for lead ions	Xing et al. 2021
Bacillus coagulansL1208	Produces bacteriocin, a potential preservative	Fu L., Wang C. and Ruan X., et al. 2018
Bacillus coagulansLBSC	Relieve irritable bowel syndrome	Maity et al. 2020
Bacillus coagulansSNZ1969	Relieve constipation symptoms and increase the number of spontaneous defecations	Kang et al. 2021
Bacillus coagulans13002	Increase the number of immune proteins and restore the level of immune factors	Zhao et al. 2021
Bacillus coagulansGBI-30	Relieve the symptoms of non-alcoholic fatty liver disease	Abhari et al. 2020
Bacillus coagulansNL01	Produced High temperature - resistant β -galactosidase	Liu P., Xie J. and Liu J., et al. 2019
Bacillus coagulansSANK70258	Promote the production of butyric acid, improve the intestinal environment	Sasaki et al. 2020
Bacillus coagulansGBI-30,6086	Regulate intestinal flora and increase the intestinal organic acid content	Nyangale et al. 2014
Bacillus coagulansGBI-30,6086	Shorten recovery time after strenuous exercise and reduce muscle soreness	Jäger et al. 2016
Bacillus coagulansGBI-30,6086	Promote the absorption of amino acids	Jäger et al. 2018
Bacillus coagulansGBI-30,6086	Enhance immunity, and relieves upper respiratory symptoms	Anaya-Loyola et al. 2019
Bacillus coagulansUniquelS2	Relieve constipation symptoms and promote defecation	Madempudi et al. 2020
Bacillus coagulansMTCC5856	Colon cells produce more of the anti-inflammatory cytokine IL-10, as well as less of the inflammatory cytokine IL-8, immune regulation	Shinde et al. 2019
Bacillus coagulansMTCC5856	Relieve symptoms of depression	Majeed et al. 2018
Unspecified	Improve feed conversion rate of chicks, promote growth	Zhang et al. 2021
Unspecified	Reduce piglet diarrhea and improve immunity	Wu et al. 2018a
Unspecified	Promote weight gain and growth of crucian carp	Yu et al. 2018
Unspecified	Protective effect on *Salmonella* infection of livestock and poultry, reduce inflammation	Zhen et al. 2018
Unspecified	The ratio of villus height to crypt depth and the amount of immunoglobulin SIgA in the duodenum were increased	Xu et al. 2017
Unspecified	Inhibited the growth and toxin gene expression of Clostridium perfringens type A	Kawarizadeh A., Tabatabaei M., et al. 2019

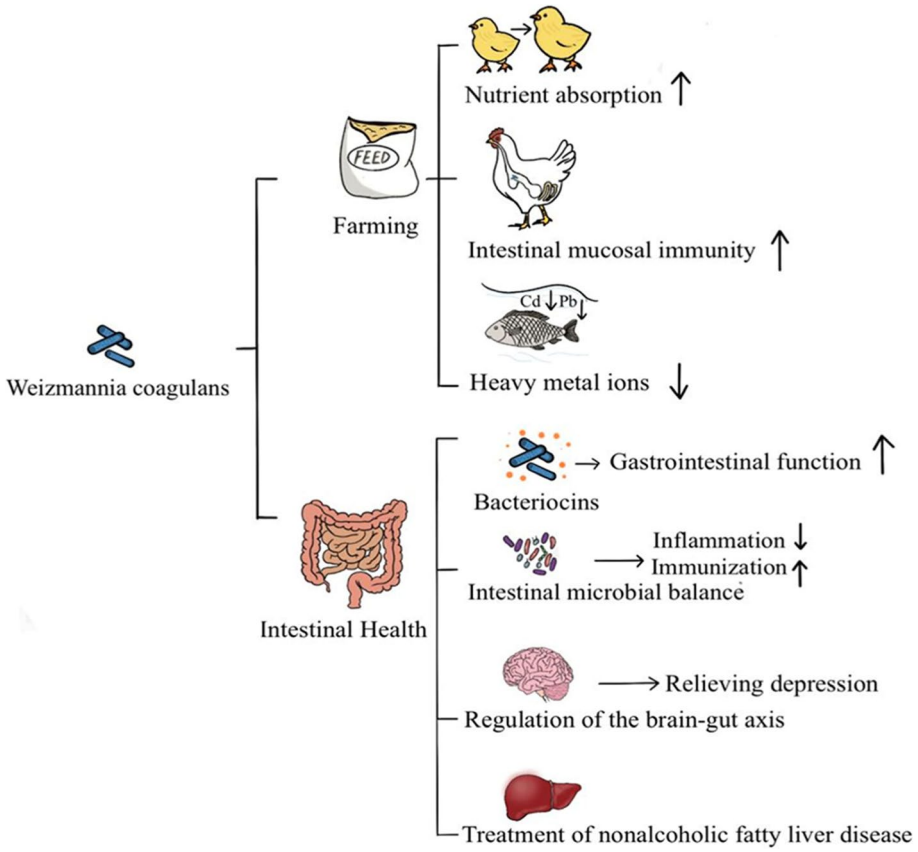

Fig. 1 Application of *Weizmannia coagulans*

Breeding industry

Enhance the nutrient absorption and growth of livestock and poultry

Good growth performance can bring a lot of economic benefits for farmers, not only improving feed utilization rate and shortening the breeding cycle but also reducing management difficulties. A large number of studies have shown that *Bacillus* can improve the growth and development of animals. *Bacillus coagulans* can not only produce a variety of digestive enzymes by themselves but also improve the host's digestive enzyme activity, which is very beneficial to enhance the absorption ability of nutrients in animals (Wang and Gu 2010; Zhou et al. 2020). A randomized trial on 480 chicks was conducted by B. Zhang et al. and the results showed that the average daily weight and the total weight of chicks fed with 5.0×10^9 CFU/kg bacteria in diet were significantly higher than those in the control group (Zhang et al. 2021). Similarly, a study on the growth performance of quails in Japan, indicates that *Bacillus coagulans* can substantially boost body weight gain and feed conversion rate (Bahrampour et al. 2020). In addition, the addition of *Bacillus coagulans* 2.0×10^7 CFU/g to piglets' feed significantly diminished the incidence of diarrhea in piglets and was beneficial to healthy growth (Wu et al. 2018a). This may be linked to the enhancement of immunity. RQ Fu et al. fed diets containing *Bacillus coagulans* during the fattening period of pigs significantly increased the intake of diets and found that serum levels of complement, interleukin 10, and lysozyme were significantly increased in pigs, indicating enhanced immunity (Fu et al. 2019). Some studies have found that *Bacillus coagulans* also plays a role in aquaculture. Compared with the control group, the weight gain rate and growth rate feeding *Carassius auratus* with a diet containing 500 mg/kg of *Bacillus coagulans* were significantly increased (Yu et al. 2018). Different doses of *Bacillus coagulans* ATCC7050 could promote the growth of *Penaeus* were obtained by Amoah et al. Meanwhile, in the experiment on *Vibrio parahaemolyticus* causing the death of prawns. It was shown that the mortality rate was negatively correlated with the intake of *Bacillus coagulans*. The cumulative mortality rate of the control group was 83.3% while the rate of the test group fed with a diet containing 1×10^8 CFU/g *Bacillus coagulans* was only 36.7%, which critically enhanced the resistance of shrimp to pathogens (Amoah et al. 2019). *Salmonella pullorum*

is one of the main pathogenic bacteria causing intestinal lesions in poultry, which is harmful to the breeding industry (Tie et al. 2018). *Bacillus coagulans* can protect livestock and poultry infected with *Salmonella* and reduce enteritis symptoms as indicated by Zhen et al. (2018). All the above studies indicate that *Bacillus coagulans* can enhance the growth performance and promote the robust growth of the animal.

Improve intestinal morphology and mucosal immunity in livestock

The small intestine is the most critical organ in the digestive system and is an essential part of nutrient digestion and absorption (Wang et al. 2020). And the ratio of intestinal villus height to crypt depth is an important index to judge the quality of nutrient absorption. The greater the ratio of the ratio, the stronger the absorption capacity of the nutrient. In 42 days, the animal experiment of C.L. Li et al. the depth of the empty intestinal crypt was significantly decreased and the villus height of jejunum increased significantly observed in the *Bacillus coagulans* TBC169 group, which means that the villus to crypt ratio of jejunum was significantly improved. But the changes were not complied with in the ileum (Li et al. 2019). However, *Bacillus coagulans* ATCC7050 had no significant effect on jejunum crypt depth in 1-day-old broilers was found by Hung et al. (Hung et al. 2012). L. Xu et al. showed that chicks fed a diet with 200 mg/kg of *Bacillus coagulans* significantly increased the villus height/crypt depth ratio at the duodenum compared to the group fed only a basal diet, the amount of the secretory immunoglobulin SIgA has also observed a significant increase (Xu et al. 2017). In a study by Y.Y. Wu et al. *Bacillus coagulans* increased the level of SIgA, an immune protein in the broiler jejunum, and promoted the expression of alkaline phosphatase and lysozyme which inhibited the growth and reproduction of pathogenic bacteria such as *Clostridium perfringens* so that the barrier function of the intestine was improved (Wu et al. 2018b).

Removal of heavy metal ions from animals

Heavy metals, such as mercury, cadmium and lead, are widely present. Since heavy metals are highly susceptible to enrichment or transfer through the food chain and will eventually endanger human health, the situation of heavy metals in animals such as livestock and poultry must be paid adequate attention (Adamse et al. 2017). It has been demonstrated that microorganisms have good protective ability against heavy metals, and the mechanism is believed to be: first, most Gram-positive bacteria can scavenge heavy metals, and the anionic groups on the surface of their bacterial bodies can adsorb heavy metal ions to reduce the entry of heavy metals into the internal environment. Second, microorganisms can defend the intestinal barrier form further damage by heavy metal ions and decrease the entry of heavy metals into the blood.

Lactobacillus and *Bacillus* have been paid more attention by the academic community because of their high peptidoglycan and teichoic-acid content. Jafarpour et al. used *Lactobacillus plantarum* and *Bacillus coagulans* blended with inulin to treat cadmium-induced rats with good results, and the rats had less liver and kidney cadmium, and their in vivo antioxidant enzyme SOD activity was markedly increased, avoiding the occurrence of severe oxidative damage. (Jafarpour et al. 2017) Similarly, XL Chang et al. confirmed the results by adding *Bacillus coagulans* SCC-19 to the feed at 1.0×10^8 CFU/g, and after 60 days of continuous feeding, carp reared in water with 0.5 mg/L of cadmium increased their body weight significantly, accumulated significantly less cadmium in the liver and kidneys than the control group, and had reduced symptoms of cadmium toxicity (Chang et al. 2021). In addition, many studies have shown that *Bacillus coagulans* R11 has excellent lead ion adsorption capacity (Xing et al. 2018, 2021). Iranian scholars have confirmed through a rat model that oral administration of *Bacillus coagulans* significantly prevented mercury toxicity, physiological indices such as creatinine and urea in rats were significantly diminished and oxidative stress was effectively alleviated (Majlesi et al. 2017). However, further studies are desired on the mechanism of metal ion removal by *Bacillus coagulans* in animals to better utilize the ability of *Bacillus coagulans* to remove heavy metal ions.

The human body's health

Resistance to gastrointestinal diseases and improvement of digestion and absorption

At present, most people tend to treat their gastrointestinal disorders by taking antibiotics. Although antibiotic drugs are fast-acting, they can readily induce resistant strains of bacteria and damage the intestinal flora. With the deepening of probiotics research, probiotics play an increasingly important role in gastrointestinal diseases. Bacteriocins and metabolites such as bacteriocin analogs produced by *Bacillus coagulans* during growth can strengthen the function of the gastrointestinal tract (Mu and Cong 2019). Moreover, *Escherichia coli*, *Staphylococcus aureus*, and *Klebsiella pneumoniae* showed sensitivity to the bacteriocin (Konuray and Erginkaya 2018). In a randomized, double-blind clinical study, *Bacillus coagulans* was affirmed to be effective and safe in the treatment of irritable bowel syndrome. Compared with placebo, symptoms of abdominal pain, constipation, and vomiting were significantly reduced in the experimental

group during the 80-day trial (Gupta and Maity 2021). Furthermore, *Bacillus coagulans* also plays an important role in alleviating the symptoms of colitis. For one study on patients with ulcerative colitis by constructing in vitro bacterial community model, it was found that *Bacillus coagulans* SANK70258 inhibited the development of harmful microorganisms in the bacterial community of patients with colitis and promoted the healthy growth of the bacterial community. Increased numbers of butyric acid-secreting bacteria, such as *Trichophytonaceae*, were observed in a beneficial flora model (Sasaki et al. 2020) and low levels of butyric acid in the gut are a leading cause of ulcerative colitis. As people get older, the human intestinal flora also changes, and the activity of probiotic flora decreases, increasing the likelihood of invasion or growth of pathogenic bacteria. After the supplementation of *Bacillus coagulans* GBI-306086, the number of *Firmicutes*, *Bacteroidetes*, and other bacteria in the feces of the elderly was considerably increased, and the concentration of intestinal organic acids was also elevated, indicating the healthy development of the intestinal microecology of the subjects were found by Nyangale et al. (2014). Likewise, *Bacillus coagulans* LBSC can revive the diversity of intestinal flora, and normalize the intestinal microenvironment so that it relieves the physiological symptoms of irritable bowel syndrome, specifically manifested in the enhanced regulation of *Actinomycetes* and *Firmicutes* (Maity et al. 2020).

Although chronic constipation is a widespread intestinal disease, the etiology is intricate and there is no specific medicine in the clinic. Lactulose, is one of the drugs generally used to alleviate constipation (Lee-Robichaud et al. 2011). A double-blind placebo-controlled study indicated that a combination of lactulose and *Bacillus coagulans* UniqueIS2 was more potent in relieving constipation in a shorter period (Venkataraman et al. 2021). In addition, in a one-month double-blind study of *Bacillus coagulans*, Indian researchers found that compared with the placebo group, the treatment group with 2 billion CFU/day of *Bacillus coagulans* had significantly more intestinal motility. Among patients, 98% of them had a healthy stool shape, and related symptoms were also relieved (Madempudi et al. 2020). One study on the relationship between *Bacillus coagulans* SNZ1969 strain and constipation was conducted by Kang et al. and it was found that compared with the control group, after taking capsules containing 1×10^9CFU *Bacillus coagulans* for 8 weeks, the colon transportation time was largely reduced, the intestinal discomfort symptoms were markedly improved as well as the times of spontaneous defecation were increased. The authors suggest that the intake of *Bacillus coagulans* improves the intestinal flora and an increase in *Lactobacillus* abundance was observed (Kang et al. 2021). However, this research only targeted young people with sporadic constipation and low fruit and vegetable intake. Whether it has the same effect on middle-aged and elderly people with chronic constipation needs to be researched. In addition, it has been shown that *Bacillus coagulans* ingestion improves stool moisture and lowers pH in people with constipation, implying an improvement in their bowel status (Saw et al. 2019).

In addition, a large number of studies have shown that *Bacillus coagulans* can promote the digestion and absorption of protein (Jäger et al. 2018). In a double-blind study of athletes, casein combined with *Bacillus coagulans* GBI-306086 significantly reduced recovery time and muscle soreness after strenuous exercise compared with casein alone (Jäger et al. 2016). A further study by Stecker et al. found that *Bacillus coagulans* GBI-306086 can promote the absorption of more amino acids in food into the blood, which means that the protein utilization rate can be improved (Stecker et al. 2020). This property of *Bacillus coagulans* will be very attractive to the elderly who have difficulty getting enough protein from their food as well as athletes and fitness enthusiasts who need to take in a large amount of protein for exercise.

The immune regulation

Human immune regulation is a complex process in which certain chemical components of the exterior cell wall of bacteria, such as *lipopolysaccharide*, *flagellins*, and *lipoproteins*, can interact directly with immune receptor cells to elicit an immune response (Zhou et al. 2020) In a double-blind randomized placebo-controlled study, 80 children who suffered from the upper respiratory tract and gastrointestinal tract infections were treated with a daily package containing 1×10^9 CFU *Bacillus coagulans* GBI-306086 powder. After a continuous 3-month intervention, the probiotics intervention significantly reduced nasal congestion, nasal mucus blood, and headaches compared to the placebo. Gastrointestinal diseases in children were also significantly improved, and the number of liquid stools fell by 45%. Likewise, the authors observed that the strain had a significant regulatory effect on immunoglobulin in serum, and the CD163 decreased by 28%, which hinted that the strain had a positive regulatory effect on the immune function of children (Anaya-Loyola et al. 2019). Shinde et al. found that spores of *Bacillus coagulans* MTCC5856 exhibit significant immunomodulatory effects by highly adhering to human colon cells, increasing the production of anti-inflammatory cytokine IL-10, and decreasing the production of inflammatory cytokine IL-8 in colon cells (Shinde et al. 2019).

Furthermore, in the study of S. Zhao et al. *Bacillus coagulans* 13002 can promote the recovery of serum immune protein and immune factor levels in immunosuppressed

mice fed cyclophosphamide (Zhao et al. 2021). It has also been reported in the literature that mice that ingested streptomycin with cyclophosphamide to suppress organism immunity caused intestinal dysfunction, and the data showed that *Bacillus coagulans* had a significant ameliorating effect, with a 75% decrease in diarrheal symptoms and a return to normal gastrointestinal function, which was better than the ingestion of products containing *Lactobacilli* and *Bifidobacteria* (Bomko et al. 2017). Furthermore, *Bacillus coagulans* also plays a regulatory role in promoting the body to revive health in chronic immune diseases. The effect of oral administration of *Bacillus coagulans* and inulin on rheumatoid arthritis model rats was studied by Abhari et al. Rats fed with 1×10^9*Bacillus coagulans* spores or synbiotics (inulin and *Bacillus coagulans*) have the same effect on reducing inflammatory factors as the conventional anti-inflammatory drug indomethacin every day. And the levels of fibrinogen and serum amyloid A were substantially lower than those of the rats fed with a standard diet, and the development of foot swelling was suppressed (Abhari et al. 2016). It has been reported that cell wall components of *Bacillus coagulans*, such as lipoteichoic acid, are immunogenic and can provoke human immune cells to induce an immune response (Jensen et al. 2017; Kang et al. 2016). Consequently, *Bacillus coagulans* has a regulatory effect on the immune system.

Relieve symptoms of depression

Depression is a prevalent psychological disorder, and according to the World Health Organization in 2015, approximately 4.4% of the global population suffers from depression, whose main clinical manifestations are low mood, loss of interest, guilt, and insomnia (Chao et al. 2020). In a report of a systematic review and meta-analysis of randomized controlled T trials, it was concluded that probiotic intake would have a favorable effect on depression intervention and there is a need for probiotics as a potential treatment for depression. (Huang et al. 2016) Endotoxin is a component of the cell wall of Gram-negative bacteria such as *Escherichia coli* and *Mycobacterium avium*, also known as lipopolysaccharide, which gets released after bacterial lysis, and as early as 2005, Danish scholars reported that endotoxin levels in humans would affect the brain's regulation of mood (Krabbe et al. 2005). Probiotic intake is thought to protect the integrity of the gastrointestinal mucosa, thereby reducing the entry of endotoxins into the bloodstream, or directly degrading lipopolysaccharide (Wallace et al. 2020).

Bacillus coagulans alters intestinal microecology, which in turn improves depressive symptoms in the host. It has been depicted that there is an association between depression and altered gut flora (Desbonnet et al. 2010). In a 90-day clinical study, 40 depressed patients were randomized to placebo or 2×10^9CFU of *Bacillus coagulans* MTCC5856 per day. The Hamilton Depression Scale (HAMD), Montgomery-Asperger Depression Scale (MADRS), and Center for Epidemiological Research Depression Scale (CES-D) in the probiotics group were remarkedly different from those in the placebo group, signifying that the quality of life of depressed patients was improved and the treatment effect was significant (Majeed et al. 2018). This result provides other new evidence that probiotics can alleviate depression. Our team found that most strains of *Bacillus coagulans* demonstrated clearance of lipopolysaccharides in vitro tests, with some strains showing up to 90% clearance. This feature may be linked to its alleviation of depressive symptoms. Nonetheless, there are few studies of *Bacillus coagulans* to alleviate or cure depression, and a lot of research is required to verify this result.

Treatment of non-alcoholic fatty liver disease

Non-alcoholic fatty liver disease (NAFLD) is a chronic liver disease with a complicated etiology that can easily develop into cirrhosis and liver cancer. About 24% of the global population suffers from NAFLD, and the situation is critical (Younossi et al. 2018). In recent years, as research on hepatic and intestinal circulation has proceeded, it has been uncovered that there is a close association between intestinal flora and NAFLD (Mokhtari et al. 2017). Currently, probiotics have been affirmed to improve symptoms of nonalcoholic fatty liver disease (Famouri et al. 2017). For in a clinical trial utilizing *Bacillus coagulans* GBI-30 in the treatment of nonalcoholic fatty liver disease, 53 patients with nonalcoholic fatty liver disease were randomized to receive either synbiotic (1×10^9*Bacillus coagulans* spores and 0.4 g inulin) or placebo. After 12 weeks, liver steatosis and serum aspartate aminotransferase (AST) and glutamine transferase (ALT) levels were significantly improved in the experimental group compared with the placebo, suggesting that *Bacillus coagulans* plus inulin is beneficial to the treatment of non-alcoholic fatty liver disease (Abhari et al. 2020). The authors did not explore the effect of single uptake of *Bacillus coagulans* on patients with nonalcoholic fatty liver disease, and further research is required.

Conclusion and prospect

Bacillus coagulans is popular in the academic community because of its unique characteristics, and many studies in recent years have shown that *Bacillus coagulans* plays an important role in several fields. This review summarizes the applications of *Bacillus coagulans* in two fields: the intake of *Bacillus coagulans* improved the growth performance of animals and enhanced their resistance to

pathogens. *Bacillus coagulans* has a considerable impact on gastrointestinal diseases and diverse chronic diseases, promoting the development of probiotic therapy.

Nonetheless, the probiotic mechanisms of *Bacillus coagulans* in promoting mucosal immunity, regulating immune function, alleviating depression and treating non-alcoholic fatty liver disease have not been sufficiently elucidated. In addition, there are many strains of *Bacillus coagulans*, and up to now, there are about 50 reports on the genome assembly and annotation of *Bacillus coagulans* in the NCBI GenBank database. The physiological and biochemical characteristics of different strains differ notably, and the probiotic functions are not the same. The strains needed to be compared by genome sequencing technology to identify the genes related to their probiotic functions so that we can develop and utilize *Bacillus coagulans* better.

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Authors' contributions
The completion of this review paper was accomplished by the collaboration of all authors. These authors have contributed equally to this work. The author(s) read and approved the final manuscript.

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Declarations

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Not applicable.

Consent for publication
All authors have read the submitted version of the manuscript and agreed to submit the work to the journal.

Competing interests
The authors declare that they have no competing interests.

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