

Research Progress of *Bacillus subtilis* in Wheat Growth Promotion and Disease Control

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Abstract: Wheat is one of the main food crops in the world, and its output is related to the world food security. In recent years, with the change of climate conditions and the overuse of chemical pesticides, the growing environment of wheat is facing severe challenges, and wheat diseases occur frequently, which seriously affects the growth and yield of wheat. As a new type of green growth promotion and control measures, biological control provides a more sustainable and environmentally friendly way for crops to cope with the challenges of the growing environment. *Bacillus subtilis* is a kind of PGPR widely found in plant rhizosphere soil. It has strong broad-spectrum antibacterial activity and resistance to stress. In this paper, the mechanism of *Bacillus subtilis* in promoting wheat growth and the control principle and effect of pathogenic bacteria in wheat were reviewed, and the existing problems were analyzed and prospected in order to provide reference for the application of *Bacillus subtilis* in agricultural field.

Keywords: *Bacillus Subtilis*; Wheat; PGPR; Abiotic Stress; Biological Control.

1. Introduction

Wheat is one of the main food crops in the world today. It belongs to the grass family and has important nutritional value. It is one of the main raw materials in many food processing industries and is widely used in feed [1], industrial raw materials [2] and biofuels [3]. Plant growth-promoting rhizobacteria (PGPR) is a kind of microorganism that interacts with plant rhizosphere and has a positive effect on Plant Growth, such as rhizobia, plant growth hormone producing bacteria and nitrogen fixing bacteria. These beneficial microorganisms establish symbiotic relationships in the rhizosphere region of plants, promote plant growth and development and resist disease through various mechanisms[4].

Bacillus subtilis is a kind of PGPR that exists widely in soil and has been widely studied for its positive effect on plants. *Bacillus subtilis* is an aerobic Gram-positive bacterium widely distributed in nature. These bacteria are rod-shaped bacteria with a rough surface, which can produce spores, have no capsule, and have peripheral flagella[5]. Under normal growth conditions, *Bacillus subtilis* can induce plant resistance, improve nutrient absorption efficiency, and produce growth hormone, which has positive effects on wheat growth and development[6]. In addition, wheat often faces environmental stress such as drought and salinization during its growth, which has a great impact on wheat growth and yield. *Bacillus subtilis* has stress resistance and can induce plant stress resistance mechanism to help wheat better cope with stress environment and maintain growth balance.

In the process of wheat growth, it is often affected by a variety of biological factors such as fungi, bacteria and viruses, resulting in the outbreak of various diseases, affecting the growth and yield of wheat, and posing a threat to global food security. There are many kinds of wheat diseases, some of the most common of which include sheath blight, rust, powdery mildew and so on. Wheat sheath blight is a fungal disease caused by *rhizoctonia trichophyta*. Symptoms include cloudy spots on stems, basal rot, seedling blight, and white

spikes. The most typical symptom in mature plants is a lesion at the base of the stem[7]. Wheat leaf rust is a disease caused by *the puccinia recondita*. It forms reddish-brown spots on wheat leaves, seriously affecting photosynthesis and nutrient absorption[8]. Powdery mildew is caused by fungi and causes leaves to be covered with powdery mildew spores, which affects photosynthesis and reduces production[9]. The use of chemical pesticides to control wheat is a common agricultural practice, however, with increasing concerns about the effects on the environment and human health, the use of chemical pesticides has also attracted widespread concern. Overuse of these pesticides in wheat control may result in a range of hazards, including potential risks to ecosystems, non-target organisms, and human health. In order to deal with this problem, biological control has become a sustainable agricultural method, and *Bacillus subtilis*, as a plant growth promoter and biocontrol bacteria, has received wide attention in the field of biological control. *Bacillus subtilis* has a certain inhibitory effect on the growth and spread of wheat pathogens. It provides a natural disease control method for wheat by competitively eliminating pathogenic microorganisms, producing antibiotics, inducing plant immunity and other ways[6].

The aim of this paper is to summarize the physiological mechanism of *Bacillus subtilis* in wheat under normal growth conditions and stress environment, and its potential application value in wheat disease control, so as to provide scientific basis and new ideas for sustainable wheat production mode and disease control strategy.

2. Characteristics of *Bacillus Subtilis*

Bacillus is an important rhizosphere bacteria. Members of this genus are the ubiquitous Gram-positive aerobic bacteria[10][11]. They have the ability to survive in harsh soil environments for long periods of time, mainly through the formation of endospores [12]. These bacteria not only have a variety of physiological properties, but also produce a large number of antibacterial compounds, making them widely

distributed in soil, waters, and animals' food and gut microbiota[13]. As part of the group of Gram-positive aerobic bacteria, members of *Bacillus* such as *Bacillus megaterium* and *Bacillus coagulans* have been identified as effective plant growth promoters (PGPR). *Bacillus* produces a large number of enzymes, antibiotics and metabolites, which makes them prominent in various fields such as pharmaceuticals and agriculture.

Bacillus subtilis is a type of Gram-positive bacteria that is widely found in the natural environment, especially soil, rhizosphere and plant surfaces. It is known for forming extremely tolerant spores, a trait that allows it to survive a variety of harsh conditions[14]. *Bacillus subtilis* has been widely studied and applied, mainly because of its various biological defense mechanisms, which can effectively protect plants from pathogenic microorganisms. These defense mechanisms include direct and indirect modes of action. Direct action is mainly through the synthesis of a variety of secondary metabolites, hormones, cell wall degrading enzymes and antioxidants to enhance plant disease resistance. Indirect effects improve overall resistance by promoting plant growth and inducing systemic resistance. In addition, *Bacillus subtilis* also has other beneficial functions, such as dissolving phosphorus in the soil, nitrogen fixation, and the formation of iron carriers, which not only promote the healthy growth of plants, but also inhibit the growth of pathogens[15].

In agriculture, the application of *Bacillus subtilis* is believed to help reduce fertilizer use while protecting the balance of soil ecosystems[16]. However, the application of this strain may also have an impact on other microbial communities in the soil, depending on the characteristics of the soil and the composition of the initial microbes[17]. Therefore, when using *Bacillus subtilis*, it is necessary to consider the dynamic changes of soil environment and microbial community in order to maximize its benefits in agricultural production.

3. Role of *Bacillus Subtilis* in the Growth of Wheat

3.1. Effects of *Bacillus Subtilis* on Wheat Growth under Normal Conditions

In general, the mechanisms of different varieties of *B. subtilis* strains promoting wheat growth are diverse. Through interaction with wheat plants, they can provide substances needed for plant growth and activate metabolic pathways, thereby promoting plant growth and having a positive impact on wheat germination and growth. Xu et al. [18] Substances that can promote wheat growth and improve nutrient acquisition of wheat seedlings were extracted from the culture environment of *Bacillus subtilis* strain YB-15 isolated from wheat rhizosphere soil : indoleacetic acid, siderophore and phosphorus solubilization, and genes related to nutrient acquisition, plant hormone production, chemotaxis and motility were found from genome analysis. Li et al.[19] Li and colleagues revealed that *Bacillus subtilis* QM3 isolated from wheat rhizosphere soil had a significant effect on wheat seed germination by comparison method, qualitative coloration, chemical dissolution experiment, β -amylase activity determination and β -amylase isoenzyme analysis. It increased the germination rate at the initial stage of germination and reduced the inhibition of cyclodextrin on germination. This *Bacillus subtilis* QM3 also significantly increased the early amylase activity of wheat seeds when

inhibited by α -cyclodextrin, and promoted the role of amylase in the process of endosperm liquefaction. Its effect was even more significant than that of exogenous NO donor SNP, which effectively promoted the germination process. In addition, *B. subtilis* can regulate the expression of β -amylase isoenzymes, which in turn promotes the germination of wheat seeds. Li et al. [20] Subsequently, Li used the same method to study the effect of *Bacillus subtilis* QM3 on the expression activity of the key enzyme α -amylase and α -amylase isoenzyme of wheat germination. It was found that *Bacillus subtilis* QM3 could increase the activity of α -amylase and the expression of α -amylase isoenzyme to effectively promote wheat seed germination. Seokjin Lee et al. [21] found that BS-L1 can promote plant growth by activating plant nitrogen signaling pathway, and significantly increase the expression of nitrate transporter *NRT2* gene.

3.2. Effects of *Bacillus Subtilis* on Wheat Growth under Adverse Environment

In recent years, the drastic change of climate conditions has led to frequent drought and flood disasters in some areas, and the problems of soil salinization and heavy metal pollution have appeared, making the growing environment of wheat increasingly severe. In this case, *Bacillus subtilis* plays an important role in wheat response to adverse environmental stress. Recent studies have shown that *Bacillus subtilis* is able to fix phosphorus in phosphate and produce iron carriers that have a positive effect on promoting wheat growth, which will benefit wheat growth in a phosphate environment[22]. Worldwide, more than 20% of agricultural land has high concentrations of NaCl. High salt leads to osmotic stress in plant cells, causing nutrient imbalances and oxidative stress damage, resulting in a 65% loss in crop yield[23][24]. High salt soil causes plants to lose water through osmotic pressure, reducing the water potential of the soil around the roots. This stress promotes the production of reactive oxygen species (ROS) in plant cells, including superoxide anions and hydrogen peroxide, which oxidize cell membranes, proteins and nucleic acids, causing oxidative damage[25]. Saboor Gul et al. [26] selected four wheat varieties to explore the effects of *Bacillus subtilis* NA2 strain on wheat growth under salt stress. The results showed that the strain could also increase the growth parameters of wheat root length. In addition, the team also found that *Bacillus subtilis* was able to increase the activity of antioxidant enzymes such as catalase to reduce the harmful effects of salt stress. *Bacillus subtilis* also has excellent protective effect on wheat in heavy metal polluted environment. For example, when *Bacillus subtilis* was added to cadmium-stressed wheat, the content of Cr^{+6} in wheat grains was significantly reduced by 90.26%. *Bacillus subtilis* also increases essential components of plant growth, such as chlorophyll, protein and relative water content, and promotes the rate of antioxidant production [27]. In addition, Dilara Maslennikova's team found that *Bacillus subtilis* could promote the lignification of wheat cell wall, thus enhancing the barrier function of the cell wall. After inoculation with *Bacillus subtilis*, the lignin content of wheat roots under cadmium stress was significantly increased compared with untreated wheat [28]. Alsu R. Lubyanova et al. [29] studied the effects of *Bacillus subtilis* 10-4 on wheat growth under drought stress. The results showed that *Bacillus subtilis* could effectively reduce the water loss and regulate the osmotic pressure of wheat cells. At the same time, electrolyte leakage in the roots and buds increased by 33 percent and 36 percent,

respectively, indicating that wheat cells showed stronger stress resistance under drought conditions after bacterial treatment. Under oil pollution stress, *Bacillus subtilis* 26D⁺ significantly decreased ROS content and MDA activity in wheat, and increased peroxidase activity and proline content, thereby alleviating the stress effect of oil pollution on plants [30]. PAs are hydrogen - and carbon-containing organic compounds formed from the incomplete combustion of biomass or fossil fuels [31]. Studies have shown that *Bacillus subtilis* NCIM 5594 can alleviate the stress effect of ANT on wheat, reduce the concentration of ANT in soil and alleviate the damage of PSI and PSII complex of wheat caused by ANT, and restore the decline in electron transfer rate caused by ANT to a certain extent [32].

4. The Role of *Bacillus Subtilis* in Wheat Disease Control

With the continuous progress of biotechnology and the development of new biological control methods, *Bacillus subtilis* has been widely concerned as a common plant growth promoting bacteria.

Fusarium is capable of causing two important wheat diseases: *Fusarium head blight (FHB or scab)*, which is characterized by the wilting of the head and developing grain, resulting in decreased yield and quality; As well as necrosis and dry rot of crown, basal stem and root tissue, commonly referred to as crown rot (CR), which reduces grain yield [33]. Studies have shown that *Bacillus subtilis* can secrete antibacterial substances to suppress and destroy pathogenic bacteria, and activate the defense mechanism of wheat cells. For example, *Bacillus subtilis* YB-15 was isolated from wheat rhizosphere soil. This strain can produce hydrolase such as β -1,3 glucanase, amylase, and antibacterial compounds such as fengycin and bacillibactin, and can induce the increase of defense enzyme activity in wheat seedling leaves, thereby reducing the resistance to F. The control effect of pseudograminearum induced *Fusarium* crown rot was up to 81.5% [18]. Eber Villa-Rodriguez et al. [34] screened and isolated the only non-hemolytic strain *Bacillus subtilis* TE3 from wheat related strains. It was found that *B. subtilis* TE3 can produce extracellular antifungal metabolites to inhibit the growth of *B. sorokiniana*, and its culture filtrate and cell suspension can significantly reduce *B. sorokiniana* infection and effectively control wheat root rot. Wang et al. [35] screened two endophytic *Bacillus subtilis*, C-01 and C-02, from highland barley seeds with broad spectrum antibacterial activity, and the two *Bacillus subtilis* had significant inhibitory effects on wheat blight pathogens and cotton verticillium, respectively. Li et al. [36] found that the inhibition rate of *Bacillus subtilis* XM-4 against wheat Scab was 82.21% by using plate confrontation method, and showed good antioxidant capacity and cellulose degradation ability.

Rhizoctonia cerealis caused by *Rhizoctonia cerealis* is an important disease that seriously harms wheat production. Studies have shown that an anti-*Rhizoctonia cerealis* protein in the metabolite of *Bacillus subtilis* Z-14. The protein has stable antifungal activity and protease resistance over a wide range of pH and temperature conditions [37]. Yang et al. [38] found that 6% Jinggangmycin ·24 billion spores /g wet-able powder produced by industry had 77.44% and 73.68% control effects on wheat stem base rot and wheat sheath blight, respectively, and could significantly increase wheat yield. Luo et al. [39] showed that 6% Jinggangmycin and *Bacillus*

subtilis wettable powder had the same control effect on wheat sheath blight as 6% pentazolol suspension seed coating. Yi et al. [40] found that the active substances produced by the metabolism of *Bacillus subtilis* XZ18-3 can damage the cell membrane and organelles of pathogenic bacteria and destroy their nuclear DNA, thus inhibiting the growth of mycelia of *Rhizoctonia cerealis*. The results showed that the control effect of *Bacillus subtilis* XZ18-3 wet powder on *Rhizoctonia cerealis* was 88.28%. Liu et al. [41] found that *Bacillus subtilis* XZ18-3 could destroy the cell membrane of *Rhizoctonia cerealis*, thus inhibiting the growth of pathogenic bacteria, and its fermentation liquid had a good inhibitory effect on pathogenic bacteria.

Take-all diseases, caused by the soil-borne fungal pathogen *Gaeumannomyces tritici* (Gt), is the world's most harmful wheat root disease, causing significant economic losses through reduced wheat yields and food quality [42]. Zhao et al. [43] isolated and screened *Bacillus subtilis* strains Z-14 and JY214, which had an antagonistic effect on Ggt growth, from soil. The results showed that under the synergistic effect of the two bacteria, the reduction rate of *Gaeumannomyces graminis* var. *tritici* (Ggt) was as high as 85.71%, and the control effect of the two bacteria applied simultaneously was as high as 73.96%. Thus, the use of pesticides was reduced and the occurrence of wheat take-all disease was effectively controlled. Xiao et al. [44] found that Fengycin and iturin A extracted from the supernatant of *Bacillus subtilis* Z-14 culture could destroy the internal structure of Ggt and induce mycelium distortion and fracture. If two kinds of antibacterial substances were applied to wheat infected with pathogenic bacteria in a certain proportion, the control effect of wheat take-all disease could reach 100%. In addition, through high-throughput sequencing of soil samples, iturin A and fengycin were also found to be effective in reducing harmful fungi in soil.

Wheat powdery mildew is one of the most serious diseases caused by *Blumeria graminis* f. sp. *tritici*. In most wheat-growing areas, powdery mildew can cause significant yield losses [45]. *Bacillus subtilis* can destroy the cell membrane of powdery mildew spores, reduce the level of MMP, induce ROS accumulation and other mechanisms to achieve inhibition, not only directly affect the growth of powdery mildew spores, but also interact with the wheat defense enzyme system to enhance the anti-fungal effect [46]. Yin et al. [47] found that the fermentation solution with 50% concentration of *Bacillus subtilis* XZ16-1 had a inhibition effect of 96.23% on the germination of Bgt spores, which could destroy the structure of Bgt cells and cause abnormal metabolism, thus inhibiting the growth of bacteria. Xie et al. [48] found that *Bacillus subtilis* TP-08 showed significant control effect on wheat powdery mildew. By using KEGG enrichment analysis, the team members found that *Bacillus subtilis* TP-08 plays a role in the control of wheat powdery mildew through the induction of terpenoid bioanabolism, chitinase activity, phenylpropyl, plant hormone signal transduction and other defense pathways. Xie et al. [49] found that *Bacillus subtilis* TP-08 could reduce the germination rate of powdery white spores and increase the sprout tube malformation rate, and induce the production of antimicrobial metabolic substances in wheat, thus achieving the effect of disease control.

In addition, *Bacillus subtilis* has also been effective in wheat stripe rust and aphid control. Zakaria et al. [50] found that *Bacillus subtilis* had significant control effect on infected

wheat stripe rust. The bacterium enhanced wheat antioxidant system by increasing the activity of *CAT*, *GR*, *SOD* and other antioxidant enzymes, so as to effectively defend against stripe rust. S. V. Veselova et al. [51] showed that the combination of *Bacillus subtilis* 26D and *Bacillus sumingiensis* B-5689 and B-6066 can produce additive effects, inducing *ISR* by enhancing the strong *SA*- and *JA*-dependent signaling pathways, and affecting *Schizaphis graminum* Rond produces a stronger aphid killing effect. *Bacillus subtilis* 26D can up-regulate the transcription of *SA* signaling pathway marker *TaRboh*, while *Bacillus thuringiensis* strains B-5689 and B-6066 can induce the transcription of *JA* signaling pathway marker *PR-6*. In addition, the three strains can also regulate the plant *REDOX* state of the pro-oxidation system and antioxidant system to improve the resistance to pests.

In addition to the study of *prosubtilis* control of wheat, another idea is to use transgenic technology to develop new strains. This approach not only enables in-depth study of unmodified natural strains, but also opens up new possibilities for modifying strains through gene editing or switching into specific genes to make them more potent against wheat. Wang et al. [52] constructed a heterogenous expression vector containing the *Cry2Aa* gene fragment of *Bacillus thuringiensis* and successfully expressed it in *Bacillus subtilis*, so that it has killing effect on lepidoptera and diptera pests. I.V. Maksimov et al. [53] successfully constructed a plasmid containing *BtcrvIIa* encoding *CryIIa* toxin from *Bacillus thuringiensis* B-5351 and introduced it into *Bacillus subtilis* 26D *CryChS*, where *CryIIa* protein was successfully expressed. The recombinant strain not only inhibited the wheat fungal pathogen *Stagonospora nodorum* Berk, but also induced plant resistance by activating *JA* and *SA* sensitivity mechanisms to obtain aphid killing activity against *S. graminum*.

5. Conclusion and Prospect

In summary, *Bacillus subtilis* plays an important role in wheat growth and disease control. *Bacillus subtilis* can promote wheat growth by producing plant hormones, nutrients and activating metabolic pathways, and improve wheat physiological parameters, including water absorption, antioxidant and osmosis, under abiotic stress such as drought and heavy metals. As a green and environmentally friendly biological control agent, *Bacillus subtilis* can produce antibacterial substances and activate the wheat defense system to protect wheat from competitors. In addition, by using gene editing technology to transfer foreign genes into *Bacillus subtilis*, it can make it have new disease resistance. Therefore, *Bacillus subtilis* can be used as a new growth promoter and control agent in wheat. However, although *Bacillus subtilis* can metabolize and produce a variety of antibacterial substances, these substances are still unable to be produced in large quantities, and it is necessary to develop an insensitive and easily fermentable fungus to produce antibacterial substances. Although the gene editing technology is becoming more and more mature, there are still few studies on the heterologous expression of *Bacillus subtilis* by this technology, and the development of recombinant bacteria by transgenic technology still needs further research. In addition, the concentration of *Bacillus subtilis* can have different effects on *Bacillus subtilis*, but the cause of this phenomenon remains to be further explored. With the in-depth study of the interaction between *Bacillus subtilis* and wheat, it is expected to provide more scientific and practical

support for its application in agricultural production, so as to further promote the sustainable development of agricultural production.

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