



Study on the Growth Promoting Mechanism and Mode of Different Nanomaterials on *Arabidopsis thaliana*

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Abstract

With the acceleration of the world population growth, soil pollution is increasing, and the demand for food is increasing. It is urgent for modern agriculture to seek an accurate, efficient and environmental protection technology to improve plant growth. At present, agricultural fertilizers and plant growth regulators are still the main application methods. Compared with traditional methods, nanotechnology is expected to be more efficient, economical, and environmental friendly. Among them, nano selenium, graphene oxide, nano-TiO₂ and carbon nanotubes have been widely used. *Arabidopsis thaliana* is considered to be one of the ideal materials for studying plant genetic engineering and crop genetic improvement because of its simple gene structure, short growth cycle and large seed quantity. Therefore, based on the biological characteristics and application value of *Arabidopsis*, this paper explores the growth promoting effect, stress resistance and mechanism of different nanomaterials on *Arabidopsis*, aiming to provide a theoretical basis for the application and promotion of plant growth of nanomaterials, and promote the application and development of nanotechnology in the agricultural field.

Subject Areas

Biomedical & Life Sciences

Keywords

Nanomaterials, *Arabidopsis thaliana*, Growth Promoting Effect, Stress Resistance

1. Introduction

With the rapid growth of the world's population, the establishment of an efficient and sustainable agricultural system is essential for human survival and development. Although the current agricultural practice can still meet the food needs of 8 billion people worldwide, the growing population and environmental changes will inevitably put forward higher requirements for the quantity and quality of food production. In this regard, nanotechnology, which is currently in the rapid development stage, is expected to become a promising tool, which can provide more accurate, efficient and environmental protection production methods for modern agricultural production.

Nanomaterials have excellent properties, and have broad prospects in biomedicine and drug delivery. As a new technology, nanomaterials have been widely used in various aspects. In recent years, nanomaterials have been applied to the field of agriculture. They can affect the process of plant growth and development and the environment in which they grow. They have the characteristics of high efficiency, economic and environmental protection, and little environmental pollution. While significantly improving plant growth, they effectively reduce environmental pollution. Its main applications include nano fertilizer, nano pesticide, nano biosensor and nanotechnology for the remediation of contaminated soil. However, the accumulation, migration and transformation of nanomaterials in plants and their enrichment in the food chain have attracted people's attention to the safety of nanomaterials.

Arabidopsis thaliana is one of the most common and valuable plants in the plant kingdom. *Arabidopsis thaliana* is small, with short growth cycle, simple genome structure, few DNA repeats and strong readability. It plays a very important role in the study of plant genetic engineering and crop genetic improvement. Therefore, the experimental research on *Arabidopsis* can promote the development and exploration of human practical knowledge in plant regulation, toxicity research and genomics research, so as to maintain the excellent quality of plants, improve plant species and environmental ecology, and realize plant cultivation and breeding.

Based on the above situation, this paper reviews the current situation of agricultural development of nanomaterials, the dynamic research of nanomaterials, the biological effects and mechanisms of nanomaterials on plants, and the biological characteristics and value of *Arabidopsis thaliana*, in order to explore the growth promoting effects and mechanisms of different nanomaterials on *Arabidopsis thaliana*, and lay the foundation for promoting the application of nanomaterials in the field of plant growth promotion and promoting the construction of ecological civilization.

2. Development Status of Agricultural Application of Nanotechnology

2.1. Nano Fertilizer

In recent decades, the substantial increase in China's agricultural output has played

a vital role in ensuring China's food security and meeting the world's food demand, and the use of chemical fertilizers is one of the fundamental reasons for increasing food production. However, traditional fertilizers are easy to pollute the environment, for example, 50% - 70% of the nitrogen in them will be lost to the environment [1], which has the problems of high cost, poor effect and low efficiency. Nanotechnology can reduce the loss of mobile nutrients, and the development of slow-release fertilizers can improve the availability of nutrients [2]. Nanostructured materials, such as hydroxyapatite, chitosan, polyacrylic acid, zeolite, etc., are developed as soil fertilizers and foliar fertilizers, which can accurately control the release of fertilizers at the required time and location, limit the loss of excess nutrients, and achieve the purpose of saving fertilizer use. Compared with conventional fertilizer, nano fertilizer has high efficiency, can significantly improve plant growth and reduce fertilizer consumption, and effectively reduce environmental pollution.

2.2. Nano Pesticides

Nanotechnology has made breakthroughs in plant pest control in recent years, laying the foundation for nanotechnology to become a powerful tool for efficient production and sustainable development of modern agriculture. Only about 0.1% of traditional pesticides can really reach the target pests, while the rest of pesticides pollute the environment and cause serious harm to human physiological health through the enrichment of the food chain. In addition, the frequent use of traditional pesticides will lead to enhanced resistance of pests and diseases to insecticides, which has brought great challenges to comprehensive management.

Nano pesticides have the potential to solve the problems of these traditional pesticides. In the presence of suitable nanoparticles, the slow degradation and controlled release of active ingredients can achieve long-term effective control of pests. Compared with traditional pesticides, it has the advantages of saving resources, low frequency of use, low cost and high efficiency. In addition, nanoparticles have stronger antimicrobial activity against fungi, bacteria and viruses. Park research shows that silicon silver nanoparticles can control the production of pathogenic fungi [3]. Therefore, nanopesticides have become a modern and efficient plant management tool, which has laid an important foundation for the application of nanotechnology in plants.

2.3. Nano Biosensor

Biosensors are receptor sensor hybrid systems for sensing the physical and chemical properties of media in the presence of biological or organic recognition elements to detect the presence of specific bioanalyzer [4]. The research of biosensors has gone through three stages. The first generation of biosensors used oxygen as the electron channel between enzyme and electrode to directly detect the reduction of enzyme reaction substrate or the production of products. Subsequently, people began to use the electronic medium of small molecules to replace the elec-

tron channel between the active center of the enzyme and the electrode, and reflect the substrate concentration change by detecting the current change of the enzyme mediator. This sensor is called the second generation biosensor. Biosensors that use direct electron transfer between themselves and electrodes to complete signal conversion are called the third generation biosensors. Biosensors have the characteristics of high sensitivity, fast response, strong stability and great potential for reuse. They are commonly used to monitor soil status, quantify total carbon, organic matter, sodium chloride, phosphate and residual nitrate in soil, and are used for soil analysis [5]. Therefore, nanotechnology has been widely used in agriculture and become a promising tool, which can provide more intelligent and efficient plant growth methods for modern agricultural practice. However, at present, the research on plant growth by nanomaterials is still in the initial stage, the relevant conclusions and technologies are still imperfect, and the relevant mechanism is still not fully explored.

3. Biological Effects and Mechanism of Nanomaterials on Plants

3.1. Absorption and Transportation of Nanomaterials in Plants

Nanomaterials have the characteristics of small size and can enter plants through roots, leaves and other organs. Studies have shown that carbon nanotubes, metal nanoparticles, and metal oxide nanomaterials can be absorbed by plants, but their absorption and function are closely related to their chemical properties.

Nanomaterials can be absorbed through the apoplast pathway and the symplast pathway in roots, and leaves can enter through stomata in addition to the above pathways [6]. In plants, nanomaterials can cross the cell membrane and enter cells through various pathways, a process known as the transmembrane process. Nanomaterials may enter cells via carrier proteins, aquaporins, ion channels, or endocytosis, thereby triggering a series of biological effects [7]. These pathways enable nanomaterials to bypass the selective barrier of the cell membrane and interact with intracellular biological processes. After the treatment of nanogold, nanogold was found in the plasmodesmata in the root of *Populus deltoides*, indicating that the transmission of nanomaterials between cells may also be through the plasmodesmata pathway. At the same time, nanomaterials can not only enter plant tissues and cells, but also be transported between tissues.

3.2. Plant Growth Regulator Effect of Nanomaterials

Plant growth regulators refer to natural or synthetic organic substances that can affect plant development and metabolic processes at low concentrations [8]. At the same time, many nanomaterials also have similar effects as plant growth regulators. Carbon-based nanomaterials are an important category of nanomaterials, including carbon nanotubes (CNTs), CDs, graphene, fullerenes, carbon nanohorns (CNH), etc. [9]. This kind of material takes the carbon element as the main framework, has little biological toxicity to plants, is easy to degrade, and can also

effectively regulate plant growth. Studies have found that single-walled carbon nanohorn (SWCNH) at a concentration of $0.1 \text{ mg}\cdot\text{L}^{-1}$ can promote the development of main roots and lateral roots in *Arabidopsis*. Gene expression analysis showed that the expression of YUC3, YUC5 and PIN2 genes related to root development were significantly up-regulated. Metabolic analysis revealed that SWCNH reconstituted carbon and nitrogen metabolism in plants, with the effects of promoting seed germination, root development and increasing fresh weight [10].

3.3. Nanomaterials and Plant Photosynthesis

The light reaction and dark reaction are two stages of photosynthesis in plants. The light reaction occurs in the chloroplast's thylakoid membrane, where light energy is absorbed by chlorophyll to produce ATP and NADPH while releasing oxygen as a byproduct. The dark reaction, also known as the Calvin cycle, takes place in the stroma and does not require light directly. It uses ATP and NADPH from the light reaction to fix carbon dioxide into glucose, completing the process of energy conversion and storage. Photosynthesis converts CO_2 in the air into organic matter through light and dark reactions. Nanomaterials will affect many key biochemical processes of light and dark reactions to improve the photosynthetic rate of plants [11]. In the process of photoreaction, nanomaterials can improve the reaction rate of photosystem by affecting the activity of PSI and PSII systems. For example, nano- TiO_2 can improve the Hill reaction rate and increase oxygen release [12]. Nano Mn accelerates water photolysis and photophosphorylation efficiency by increasing CP43 protein activity in Mn_4Ca complex of PSII system [13]. Some nanomaterials are good conductors that can accelerate the electron transfer rate in photoreactions [14].

In the dark reaction stage, nanomaterials can affect the dark reaction efficiency by regulating stomatal conductance and key rate limiting enzyme activity [15]. In the study of *Arabidopsis thaliana*, it was found that nano Fe could up regulate the expression of membrane H^+ -ATPase synthesis gene AHA2 by 5 times, promote stomatal opening, and thus affect the photosynthetic rate [16].

3.4. Nanomaterials and Plant Stress

With the rapid development of industrialization and the discharge of waste water, the pollution of heavy metals in soil and the deterioration of saline alkali land are increasing. Therefore, the importance of studying the effect of nanomaterials on plant stress resistance is self-evident.

As abiotic enzymes, some nanomaterials have great potential in improving plant stress resistance, which can improve plant drought resistance, salt resistance, heavy metal stress resistance, etc. In terms of biological stress, nanomaterials have excellent ability to reproduce pathogenic microorganisms and reduce the degree of plant diseases. Single walled carbon nanotubes, graphene, and graphene oxide all have certain antifungal pathogen resistance, among which single-walled carbon nanotubes are the best. In the study of *Fusarium graminearum*, it was found that

500 $\mu\text{g}\cdot\text{mL}^{-1}$ single-walled nanotubes reduced its spore germination rate by 95.2%. In addition, nano-TiO₂, nano ZnO, copper-based and silver-based nanoparticles also have excellent broad-spectrum antibacterial ability [17]. Therefore, the application of nanomaterials in the field of plant stress has broad prospects.

4. Biological Characteristics and Value of *Arabidopsis Thaliana*

Arabidopsis thaliana belongs to the genus *Arabidopsis* of Cruciferae and is widely distributed in Europe, Asia, Africa, Australia and North America. It has all the characteristics of flowering plants and makes it a model species for plant genetic research. *Arabidopsis thaliana* is not only small in size, short in growth cycle, large in seed quantity and abundant in mutants, but also has a very small genome and few repetitive sequences. These characteristics make it a model species of *Drosophila* in plants and molecular biology research; The continuous deepening of its research provides good materials for the theoretical and applied research of plant genetics and breeding. Therefore, its important position in plant genetic engineering and crop genetic improvement has also received increasing attention. In practice, it is also possible to isolate some excellent genes of *Arabidopsis thaliana*, and then transfer them to other crops through transgenic technology, so as to obtain important genetic information and produce greater economic benefits.

5. Prospect

With the rapid growth of the world economy, the problem of food shortage caused by the rapid expansion of the population has become increasingly prominent. Modern agriculture has put forward higher requirements for more efficient and economical plant growth promotion technology. Nanotechnology is a technology that organically applies nanomaterials to plant growth promotion through nano fertilizers, nano pesticides, nano biosensors and other ways. Compared with traditional growth promotion methods, nanotechnology has a broad application prospect due to its high efficiency, environmental protection, economy, precision and other characteristics. It is a very promising tool, but there are still many problems that have not been solved in the current practical application, and the relevant mechanism has not been explored.

Because of its short growth cycle, abundant mutants, simple genome structure and other characteristics, *Arabidopsis* occupies a very important position in the fields of molecular biology, plant genetic engineering and plant genetic research in China. It has been confirmed that the related nanomaterials have a promoting effect on its growth. At present, the effects of nanomaterials on promoting plant growth and reproduction and enhancing plant stress resistance have been explored. Some appropriate concentrations of nanomaterials have a growth-promoting effect on *Arabidopsis* to a certain extent. Therefore, it is of great practical significance to explore the growth-promoting effect, stress resistance and action mechanism of nanomaterials on *Arabidopsis*, which provides a theoretical basis

for the application of nanomaterials in the field of plant growth promotion.

At present, nanotechnology has become increasingly mature and perfect. However, it still needs to consider the specific growth environment of different plants and explore appropriate technology combinations and optimization schemes to truly apply it to specific scenarios and achieve the ideal growth promotion effect. Although the potential of nanomaterials in mitigating stress in *Arabidopsis thaliana* has been fully validated, their application must take into account potential environmental and health risks. Nanoparticles may adversely affect soil microbial communities, ecosystem stability, and human health, while their environmental persistence and cumulative effects remain insufficiently studied. Therefore, future research should focus on developing green synthesis methods and environmentally friendly nanomaterials to reduce their ecological toxicity, as well as optimizing the biodegradability of nanomaterials to minimize their environmental residues. Given the high cost of nanotechnology, efforts should also be made to enhance production efficiency, promote large-scale applications, and utilize sustainable raw materials to achieve a balance between cost and effectiveness, thereby facilitating the broader application of nanotechnology in agriculture. In this paper, the agricultural development status of nanomaterials, the dynamic research of nanomaterials, the biological effects and mechanism of nanomaterials on plants, the biological characteristics and value of *Arabidopsis thaliana* were reviewed. The nanomaterials with growth-promoting effect were screened, and the physiological response and regulation mechanism of the optimal nanomaterials on *Arabidopsis thaliana* were explored, so as to explore a more efficient and economical technical scheme, provide new ideas and theoretical basis for promoting plant growth and reproduction, and better apply nanotechnology to plant physiological research and agricultural production.

Conflicts of Interest

The authors declare no conflicts of interest.

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