



Study on the Growth and Physiological Responses of *Helianthus tuberosus* L. under Salt Stress with Exogenous Silicon

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Abstract

As an important cash crop in China, Jerusalem artichoke is widely used in ecological protection, vegetable development, industrial and animal husbandry production and other directions, and has important production value. However, under the background of global warming, soil salinization has become increasingly serious, which has become one of the important factors endangering crop production. The adverse stress caused by salt in soil to plants includes osmotic stress and salt toxicity stress, which causes physiological drought and water extravasation in roots, and then suppresses the normal plants' vegetation growth and reproduction. Silicon is the second most abundant oxygen element in the crust of the earth, which attracts much attention because it improves crop resistance to multiple stress environments. Therefore, based on the occurrence of drought salt stress in Jerusalem artichoke planting, this paper deeply explores the physiological response of plants to drought salt, and comprehensively analyzes the comprehensive regulation effect of exogenous silicon on drought stress and salt stress. This paper reviews the research on silicon's regulation of plant drought and salt tolerance at home and abroad, analyzes the effects of silicon on the growth and development, photosynthesis and respiration of plants under drought and salt stress, with the aim of providing theoretical basis for related theoretical research and the application of silicon fertilizer in agricultural production.

Subject Areas

Plant Physiology

Keywords

Helianthus tuberosus L., Drought Salt Stress, Silicon Addition

1. Introduction

Under the background of global changes, the change of precipitation pattern and the large development of industry and agriculture, a large area of farmland in China is faced with the dual dilemma of soil salinization and drought stress, and the ecological environment and agricultural production are greatly threatened. Due to climate change, unreasonable agricultural production activities and other reasons, the global area of saline-alkali land reached 954.38 million hectares, and China reached 99.13 million hectares, and the area and salt content are still increasing [1]. As one of the major arid countries in the world, the arid area of China is about 2.8 million square kilometers, accounting for about 24.6% of China's total land area. The losses caused by drought disasters rank first among the total losses caused by various natural disasters [2]. Drought stress seriously affects the growth, development and reproduction of plants, and causes serious constraints on the morphological structure and physiological function of plants [3]. Salt stress can inhibit the normal growth of plants through various mechanisms such as osmosis effect, ion toxicity, nutrient deficiency and oxidation, resulting in low germination rate, decreased photosynthetic rate and water and nutrient imbalance [4]. It also poses great harm to ecosystem stability and human health. Nowadays, there is more exploration about the dynamic changes of plant growth physiology under the single stress of salt and drought, but less exploration under the background of dual stress.

Jerusalem artichoke (*Helianthus tuberosus* L.), the family Asteraceae (Asteraceae), the genus sunflower (*Helianthus* L.), is a perennial herb, origin located in the Great Lakes region of North America, adapted to a variety of climatic conditions. It has the dual effect of both medicine and food, and also plays an important role in the preparation of chemicals and microbial fermentation, and also has the energy value of biomass, so it is widely used in human life. As one of the planting areas of Jerusalem artichoke, Zhejiang province is also the disease salinization distribution area, and the soil is slightly acidic. In addition to climate reasons, the uneven distribution of water resources in time and space, and the influence of population and water resources utilization rate make drought more serious. Therefore, it is urgent to study the mechanism of drought-resistant salt of Jerusalem artichoke and find ways to alleviate stress. At present, it is found that Silicon (Si) has a significant positive effect on the growth and development of plants, which can enhance the negative effects of plants against biological stresses and abiotic stresses such as drought, salt damage, heavy metals, etc. However, the growth and physiological response of Jerusalem artichoke under drought salt stress, so it is of great theoretical and practical significance to improve the quality of the production of Jerusalem artichoke and expand its planting range. This paper aims to present the value and biological characteristics of Jerusalem artichoke, drought and salt stress conditions, plant responses to drought and salt stress, and the physiological regulation of drought and salt stress resistance in plants under adverse conditions, as well as propose strategies for adding silicon to alleviate Jerusalem artichoke drought

and salt stress, providing theoretical guidance and technical support for improving the quality and yield of Jerusalem artichoke, while reducing the damage to other plants under drought and salt stress conditions.

2. Biological Properties and Value of Jerusalem Artichoke

Jerusalem artichoke for chrysanthemum family (Asteraceae) sunflower (*Helianthus* L.) perennial root herbs, also known as artiker, devil ginger, its rich in inulin, can be used as a biological fermentation, production of ethanol and a good source of oil, with heat cool blood and water dehumidification effect, is an important economic crops in our country, has a broad application prospect. Jerusalem artichoke has high ecological adaptability, drought tolerance, cold tolerance and salt-alkali tolerance, and strong regeneration ability. Seed can take root on the ground and reproduce everywhere, and its underground tuber can also be propagated asexually. It is a kind of cultivated plant with low requirements for living environment and diverse functions. Jerusalem artichoke adaptability to soil adaptability, can grow in $EC_e < 30$ d S/m, it also has certain resistance under metal stress, root vitality under metal stress, and low concentration of single acid, single aluminum stress makes its superoxide dismutase (Superoxide Dismutase, SOD) activity are increased, antioxidant enzyme activity coordination, make it has strong stress resistance. In recent years, we mainly focus on germplasm resources, kinship and salinity stress, while there are few studies on acid and aluminum resistance of Jerusalem artichoke [5]. Compared with normal Jerusalem artichoke, the plant height was reduced by 66.80%, the number of flowering was reduced by 97.40%, the number of branches at the base of the main stem was reduced by 51.52%, and the number of nodes in the main stem was reduced by 74.60%.

3. Dynamic of Salt and Cadmium Stress

3.1. Soil Salinization and Drought Status Quo

3.1.1. Status of Soil Salinization

Soil salinization is a global problem that restricts agricultural development and threatens food production safety. According to statistics, the hazard of salt causes the global annual new failed arable land area $(0.3 - 1.5) \times 10^6$ hm², Production cultivated area $(0.20 - 0.46) \times 10^6$ hm². The existing irrigated agricultural farmland area in the world is 2.3×10^8 hm², About 20% of them have been affected by different degrees of salinization, and due to the continuous impact of global climate change and unreasonable agricultural activities. It is expected that by 2050, this proportion will be further expanded to 50%, leading to the sustainable development of China's agriculture [6], crop yield reduction of 18% - 43%.

3.1.2. Soil Drought Status Quo

Soil drought is the most important cause of plant decline or death. Since the 1970s, the frequency and intensity of extreme climate events such as drought caused by global warming have increased significantly [7], and have had a huge and far-reaching impact on global agricultural production and food security. Drought events in

China, crops affected by drought area accounted for more than 50% of the total affected area, the world hungry population in 2014 trend reversal, after increasing trend, and in 2015-2016 strong El Niño, phenomenon caused by severe drought further lead to the global more serious food crisis, a serious impact on global food supply and food prices [8].

3.2. Response of Plant to Drought Salt Stress

3.2.1. Photosynthetic System of Plants Damaged by Drought Salt Stress

Photosynthesis is a particularly important process of plant growth and the only energy source of plants. The level of photosynthesis effect directly affects the accumulation of plant biomass, and photosynthates provide energy for plant metabolism and mitigation of biological and non-biotic stresses [9]. Photosynthetic system is an important function of photosynthesis, and its integrity and high efficiency ensure the normal physiological activities and the accumulation of organic substances in plants, so as to promote plant growth and development. Photosynthesis is the physiological process that plants are most sensitive to various abiotic stresses [10]. Under stress conditions, plant leaf growth slows or wilts, and the photosynthetic system is destroyed, resulting in less fixed energy of plant photosynthesis. Meanwhile, stress response processes such as osmoregulatory substance metabolism and reactive oxygen species removal make plants consume more energy than under normal growth conditions. The study showed that both salt stress and drought stress lead to the reduction of photosynthetic pigment content in plant leaves, affect leaf gas exchange, reduce photosynthetic carbon assimilation products, seriously affect photosynthetic capacity, and eventually lead to crop production [11].

3.2.2. Effects of Drought Salt Stress on the Activity of Plant Antioxidant Enzymes

ROS is an important signaling molecule in plant stress response, and ROS over accumulates in plants under drought salt stress. The plant antioxidant enzyme system is mainly composed of superoxide dismutase (Superoxide Dismutase, SOD), peroxidase (Peroxidase, POD) and catalase (Catalases, CAT), which can clear ROS and protect the structural stability of the cell membrane. Among them, SOD specifically clear $\cdot O_2^-$, POD and CAT then clear its product H_2O_2 [12]. Under stress conditions, the cell homeostasis in plants is broken, and the production and removal of ROS are unbalanced, which makes the cell antioxidant system overload, producing oxidative stress, leading to enzyme inactivation and other phenomena [13]. However, plants can cooperate with SOD, POD and CAT to maintain the reactive oxygen species at a low level, slowing down or defending against aluminum stress to a certain extent. Research points out that [14] dual stress of drought salt can lead to increased SOD, POD and CAT activities in plants, which can remove excess ROS in a short period. However, with the extension of drought salt stress time and the deepening of stress, this protective function gradually decreases and even collapses.

3.2.3. Drought Salt Stress Disrupts Osmotic Regulation and Ion Balance in Plants

Salt stress mainly caused osmotic stress and ion stress on plant growth. Osmotic stress induced by salt stress induces biosynthesis and accumulation of osmolytic material to reduce cell osmotic potential to stabilize protein and cellular structures. The high concentration of salt in the soil reduces the soil water potential, making it difficult for plants to absorb water, causing water extravasation in the plant, leading to water loss of cells, affecting a series of metabolic reactions of cells, thus inhibiting plant growth [15]. After growing in a high salt environment for a period of time, the salt accumulates mainly one or two ions in the plant, inhibiting the absorption of other ions. Plants accumulate an excess of Na under salt stress, owing to Na⁺ take part in Ca²⁺ Ionic radii are very similar, with Na in the cytoplasm and exoplasm. The concentration rises, the plasma membrane, vacuole membrane, chloroplast membrane and other cell membranes on the Ca²⁺. After replacement, the membrane structure is destroyed, the selective loss of the membrane, not only make the cell metabolism disorder, but also lead to the plant nutrition disorders, aging in advance, so that the plant can not grow normally [16].

The central problem of drought stress is protoplasm dehydration. Due to the effective water loss in the soil during drought, the transpiration of the plant leaves was not replenished, which dehydrated the protoplasm, increased the permeability of the native plasma membrane, decreased the cell water potential, reduced the swelling pressure, and the growth, development and physiological process of the plant are inhibited [17]. Under conditions of high permeability such as drought, plants can reduce cell penetration potential through osmoregulation, so as to increase water absorption to maintain cell water content and turgor pressure, and maintain the normal physiological metabolic activities of cells, which is one of the main physiological mechanisms for plants to adapt to drought stress. Plant cell osmoregulation depends on the synthesis and accumulation of soluble substances to promote osmotic balance and water uptake and retention. These solutes include amino acids (proline, glutamic acid), soluble sugars (fructan, trehalose, sucrose, oligosaccharides), polyols (mannitol, sorbitol), betaine, carnitine and other small molecular organic matter, K⁺, Cl⁻, Na⁺ Such as inorganic ions [18] [19]. Studies have shown that dry early stress increases the proline content in rice plants, and rice varieties with strong early tolerance accumulate more proline than sensitive varieties [20].

3.3. Relief Countermeasures of Salt and Cadmium Stress

3.3.1. Remission Effect of Exogenous Substances on Salt Stress in Plants

In the past, soil improvement schemes required a lot of manpower and material resources. In recent years, salt-resistant varieties have been obtained through traditional hybrid breeding, seawater irrigation screening breeding, transgenic and other methods, but no large-scale salt-resistant varieties have been cultivated. Exogenous hormones is a lower cost, environmentally friendly and efficient way. Studies have shown that salicylic acid (salicylic acid, SA), abscisic acid (abscisic

acid, ABA), melatonin (melatonin, MT) can reduce the damage of environmental stress to some plants. Therefore, it is crucial to regulate the plant metabolic processes through the rational selection of exogenous hormones.

3.3.2. Mitigating Effect of Exogenous Substances on Plant Drought Stress

In the study of pen-holder tree seedlings [21], leaf spray exogenous material can significantly improve the leaf antioxidant enzyme activity, effectively remove too much reactive oxygen in the cell, significantly reduce the relative conductivity and malondialdehyde content, cell membrane system metabolism normal, reduce drought stress to pen tree seedlings damage, and improve the net photosynthetic rate, stomatal conductivity, transpiration rate and chlorophyll content, effectively reduce the drought stress of the inhibition of photosynthesis. Exogenous melatonin can effectively alleviate plant physiology and rhizosphere soil under drought [22]. Methyl jasmonate (MeJA) can relieve the normal growth, development and physiological characteristics of potato seedlings through photosystem and hormonal regulation [23]. Methylglyoxal (MG) has a positive effect on improving the drought resistance of Chinese chestnut seedlings in attenuating the peroxidative damage of membrane lipids [13].

4. Regulation of Exogenous Silicon on Plants

4.1. Physiological Properties of Silicon

Silicon (Si) is the second largest element in the earth's crust after oxygen, accounting for about 28.8% of the earth's crust composition [24]. Higher plants absorb soluble silicon from the soil through their roots and are deposited in plant tissues as planted silicon bodies. Silicon is an important nutrient element in the response of plant adversity. Studies have shown that silicon plays an important role in improving soil environment, promoting crop growth, improving the content of photosynthetic pigment, antioxidant enzymes, osmotic substance content and nutrient absorption in plants [25]. In addition, silicon can improve water status, participate in plant metabolic activities and gene expression, mediate energy dissipation, affect photosynthetic activity, antioxidant defense system and the balance of mineral elements in plant body reduce drought stress to plant damage, effectively improve drought tolerance under drought stress, increase crop yield [26].

4.2. Effect of Exogenous Silicon on the Growth Morphology of Plants under Drought and Salt Stress

Plant stem, leaf and root lineage are key components of adaptation to stress, and their external morphological characteristics and internal anatomy best reflect the adaptability to adversity [27]. Under drought stress, plant leaves show etiolation, atrophy, curli, senescence and even abscission. In salt stress, it leads to short stature, smaller leaf area, delayed delay, and reduced yield. Sibole *et al.* [28] reported that salt stress inhibited stem and petiole growth in *C. alfalfa*. During plant adaptation, stress induces complex changes in leaf thickness, palisade organization,

and sponge tissue. Zheng *et al.* [29] found that drought stress increased the thickness of barbary wolfberry leaf fence tissue and reduced the thickness of sponge tissue, thus inhibiting transpiration and preventing excessive tissue dehydration. Yao *et al.* [30] found that barbary wolfberry leaf thickness, width and leaf length increased significantly with increasing salt concentration under salt stress, and low salt mainly promoted it, but high salt concentration mainly increased the thickness of palisade tissue and thus increased leaf thickness. In the study of rice, silicon alleviated the toxicity of cadmium on the growth and development of rice seedlings, and reduced the cadmium content in all parts of the plant [31]. Silicon can promote plant root growth, improve root development and improve water conductivity of roots [32], promote water and nutrient uptake, thereby enhancing plant stress resistance, contributed to the increase in biological production 24% - 39%.

4.3. Effect of Exogenous Silicon on Plant Photosynthesis under Drought and Salt Stress

The decrease in photosynthetic pigment content closely corto the excessive accumulation of reactive oxygen species under stress conditions [33]. Silicon can increase chloroplast size, particle number, and chlorophyll content, thereby enhancing photosynthesis [34]. Silicon application significantly alleviated the effect of stress on chlorophyll content in sugarcane, licorice, peanut, tomato, and wheat. Shen *et al.* [35] found that under salt stress, the application of silicon to licorice leaves reduced the decomposition of chlorophyll, promoted the transport of water and the production and transport of organic matter, thus promoting photosynthesis. In Teixeira *et al.* and Zhang *et al.*, we showed that silicon increased the concentration of chlorophyll and carotenoids in sugarcane seedlings and tomato seedlings under drought stress [36]. Appropriate application of silicon can significantly improve the photosynthetic performance of plants under stress conditions, promote photosynthesis, and improve plant stress resistance [37]. Improve the maximum photochemical quantum yield (Fv/Fm) and actual quantum yield of PS under drought and salt stress; Li *et al.* found that silicon significantly increased the activity of photosynthesis-related enzymes, such as ferredoxin-NADP reductase (FNR), ATP synthase and ribose-1,5-diphosphate carboxylase/oxygenase (Rubisco) in cotton seedlings under salt stress, thus promoting photosynthesis.

4.4. Regulation of Metabolism-Related Enzyme Activity and Organic Acid Content by Exogenous Silicon

Respiratory metabolism has high plasticity, and plants change respiratory metabolic pathways in response to stress, while silicon can also improve plant stress resistance by regulating respiratory metabolic pathways. The study showed that silicon regulated TCA metabolism of millet seedlings under drought stress, and promoted the shift of acetyl coenzyme A to lipid biosynthesis, so as to enhance osmotic stress tolerance; in the study of rice, silicon changed the enzyme activity

in TCA cycle under salt stress, significantly increased the organic acid content, alleviated the inhibitory effect of salt stress on TCA cycle of rice seedlings, and improved the salt tolerance. The study showed that silicon significantly increased the cytosolic glucose-6-phosphate dehydrogenase (G 6 PDH) activity, and enhanced the tolerance of barley to alkali stress [38]. It was found that silicon significantly increased the activity of phosphoglucose isomerase (PGI), G-6-PDH, 6-phosphogluconate dehydrogenase (6-PGDH) and malate dehydrogenase (MDH) in the roots of rice seedlings [39], thus providing more ATP for plant life activities.

5. Conclusions

In recent years, climate change, excessive fertilization, unreasonable irrigation and other reasons have made soil acidification more and more serious, and the influence of dry salt is increasing. However, exogenous silicon can effectively alleviate the inhibitory effect of stress on plant growth and promote biomass accumulation. Maintaining photosynthetic and respiratory metabolism is one of the important means to enhance salt tolerance in plants. Silicon can improve the function of photosynthetic system by protecting the structure of leaf photosystem structure, increasing chlorophyll content and reducing oxidative stress; increase water use efficiency by increasing stomatal conductance and reducing transpiration water loss; promote plant photosynthesis by improving light energy utilization and carbon fixation process, and provide more ATP for plant life activities to resist stress. At present, there have been many theories on silicon to improve drought tolerance in plants, but there are still many problems to be solved.

Based on the above background, this paper aims to review the *in silico*-mediated mechanisms of salt and drought tolerance in plants. We plan to use Pujiang Jerusalem artichoke, a native species of Zhejiang, as the experimental material. We will establish a reasonable aluminum concentration gradient and apply different boron concentration gradients to the seedlings. By analyzing plant height, root length, MDA content, antioxidant enzyme activity, chlorophyll content, superoxide anion levels, DNA damage, root vitality, root tip aluminum ion content, and organic acid index, we will comprehensively evaluate the stress level of the taro from morphological, physiological, molecular, and photosynthetic perspectives. This comprehensive evaluation aims to provide certain theoretical guidance for actual production. Most current studies focus on a single stress factor, either drought or salt. However, in nature, plants are subjected to both drought and salt stress simultaneously. Therefore, the regulatory effects and mechanisms of silicon on plants under dry salt dual stress need to be revealed. Although the regulation of physiological and biochemical metabolism to alleviate drought salt stress, the deep mechanism has not been clarified. In future studies, emerging technologies such as molecular biology and multi-omics can be combined to conduct deeper research, and more systematically and comprehensively reveal the physiological and molecular mechanisms of silicon to enhance plant salt and drought tolerance.

Conflicts of Interest

The authors declare no conflicts of interest.

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