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Studies on the Response of Water Regulation to Growth and Physiological Characteristics of Potato

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Abstract: As an important cash crop in arid and semi-arid regions, potato plays a vital role in both economic growth and food security. Due to its high sensitivity to water availability, water stress frequently occurs during potato cultivation, posing a major constraint to its sustainable production. This paper presents a comprehensive review of existing studies on the effects of water regulation on potato growth, physiological traits, yield, and quality. It outlines the influence of water stress on morphological parameters, photosynthetic performance, stress-related physiological responses, and yield components, and discusses future research directions, aiming to offer a theoretical foundation for subsequent investigations.

Keywords: potato; water regulation; growth and development; physiological characteristics; yield

1. Introduction

Moisture plays a crucial role in crop production. In recent years, global climate warming and the increased frequency of extreme weather events have intensified meteorological droughts, becoming major limiting factors for agricultural development in China [1]. Water scarcity presents a significant global challenge. Although China possesses only 6% of the world's freshwater resources, its per capita availability is merely one-quarter of the global average, leading to its classification by the United Nations as one of the 13 water-stressed countries. Currently, China's water resource utilization rate stands at just 40%-50%, which is 20%-30% lower than that of developed nations, and a large proportion of its arable land is situated in arid and semi-arid zones [2]. According to the *China Water Resources Bulletin 2023*, the agricultural sector consumed 367.24 billion m^3 of water, representing 62.2% of the nation's total water usage. Although this amount is 10.89 billion m^3 less than in 2022, the proportion increased by 2.2% [3]. Thus, improving water use efficiency is essential for the sustainable growth of agriculture in China.

Potato (Solanum tuberosum L.), a member of the Solanaceae family, is an annual herbaceous plant known for its adaptability, high productivity, and nutritional value. It is cultivated globally and ranks as the fourth most important food crop after maize, wheat, and rice [4]. China is a leading potato producer, with approximately 70 million mu under cultivation and an annual yield of 94.36 million tons — both figures ranking first worldwide [5]. As a major staple crop, potato production plays an important role in supporting national food security and enhancing agricultural capacity [6]. However, current potato

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yields in China remain significantly lower than those in developed regions such as Europe and North America, indicating substantial potential for improvement. This study focuses on how water regulation influences potato growth, physiological responses, and yield quality, aiming to contribute theoretical support for enhancing both agricultural productivity and water resource efficiency.

2. Impact of Water Regulation on Potato Growth and Development

Water is essential for crop growth and development. It plays a crucial role in photosynthesis, the synthesis, breakdown, and transportation of organic matter in potatoes, and in supporting normal physiological processes, including nutrient absorption in the root system. Research on water productivity under drip irrigation in an oasis indicated that regulating water during the tuber formation stage not only enhances irrigation efficiency but also increases potato starch content and dry matter formation [7]. In studies on the effects of varying water supplies on potato growth, it was found that as irrigation increased, potato plant height, stem thickness, leaf area, and dry matter accumulation per plant also increased, reaching a peak when the field water holding capacity was between 75% and 85% [8]. Other findings showed that during the seedling stage, optimal soil moisture content between 82% and 91% resulted in a 100% emergence rate, while exceeding 91% caused a significant drop to just 30%. Insufficient moisture (below 82%) prolonged emergence and reduced growth rate. During the tuber formation period, soil moisture content between 85% and 91% promoted optimal plant height, stem thickness, leaf number, root fresh weight, and vigor. This stage is critical for potato development, as water stress severely affects plant height, root length, and yield. These observations align with studies on the negative effects of water stress on stem tuber development, where greater water stress results in shorter plants and smaller tubers [9,10]. Further research has shown that water deficit during the seedling stage significantly enhances potato plant height, root length, and tuber yield compared to controls. In response to drought stress, potatoes develop longer roots and increased root vigor to counteract stress, although severe drought can lead to root cell death [11,12]. In summary, water stress affects yield formation, and in agricultural practice, timely water regulation and methods such as "squatting seedlings" can improve drought resistance and synchronize nutrient and reproductive growth, thereby increasing potato yields.

3. Effects of Water Regulation on the Physiological Characteristics of Potato

3.1. Effects on Photosynthetic Indicators

Leaves serve as the primary organs for vital physiological functions such as photosynthesis and transpiration, which have a direct influence on crop productivity. Under drought conditions, these physiological activities in potatoes are significantly disrupted. Stomatal closure in response to water deficiency reduces CO_2 uptake, lowers the photosynthetic rate, and ultimately leads to decreased yields and reduced water use efficiency. Studies have shown that drought stress results in a decline in light-related indicators and chlorophyll content in potato leaves as the stress level increases. Additional research observed that with intensifying water stress, indicators such as SPAD values, net photosynthetic rate (Pn), transpiration rate (Tr), stomatal conductance (Gs), and intercellular CO_2 concentration (Ci) initially rise and then fall, indicating that water availability plays a crucial role in photosynthetic performance and yield formation. Potatoes respond to water stress primarily through the closure of stomata, limiting gas exchange and suppressing photosynthetic activity. Severe drought can also impair the activity of photosynthetic enzymes, further reducing photosynthesis efficiency. Experimental results show that parameters like Pn, Gs, Ci, Tr, and chlorophyll content of potato leaves all decline markedly as drought becomes more severe, thereby restricting leaf assimilation capacity and lowering yield potential [12]. Moreover, differences in

irrigation methods and potato cultivars can lead to variations in these physiological indicators.

3.2. Effects on Physiological Indicators of Adversity

Under optimal moisture conditions, reactive oxygen species (ROS) within plants remain balanced, supporting normal physiological development. However, as water stress intensifies, excessive ROS accumulate alongside malondialdehyde (MDA), a byproduct of membrane lipid peroxidation, and free proline (Pro), leading to membrane damage and disruption of key biochemical processes. Water deficit typically reduces relative water content, inhibits protein synthesis, and significantly raises MDA levels. In drought-tolerant crops, moderate water stress tends to increase the activity of antioxidant enzymes such as superoxide dismutase (SOD), enhancing ROS scavenging capacity. Potato plants activate both enzymatic and non-enzymatic antioxidant defenses to mitigate oxidative damage under drought conditions. Research has indicated that brief periods of water stress during the tuber expansion stage may not be harmful; instead, they can stimulate physiological responses favorable to growth. For instance, SOD and peroxidase (POD) activities in potato leaves during flowering and tuber enlargement were significantly higher under mild to moderate drought than under normal conditions, with notable increases in osmoprotective compounds such as proline. Under moderate to severe drought during flowering, proline concentrations rose to 2.7 times that of the control group [2]. Additionally, drought resistance in potato is closely linked to the regulation of osmotic substances, including proteins, soluble sugars, and Pro. Higher soluble sugar levels are typically associated with improved stress tolerance. As drought persists, proline accumulation intensifies, though osmotic regulation declines when stress surpasses a critical threshold [11]. These findings underscore the essential role of antioxidant enzymes (particularly SOD and POD) and osmotic adjustment substances (Pro and soluble sugars) in maintaining homeostasis under water-limited conditions.

3.3. Impact of Water Regulation on Yield and Quality

Moisture directly influences both the yield and quality of potatoes. Studies have shown that short-term water deficits can have a positive effect on tuber development and overall yield [12]. During early growth stages, moderate water reduction alters dry matter distribution among plant organs, with an increased allocation to roots, which may ultimately enhance yield. Similar results were reported in studies on potatoes and cereal crops, indicating that rewatering after drought stress at the seedling stage facilitates rapid dry matter accumulation, compensating for the effects of prior water deficits. Water stress applied during the starch accumulation phase has minimal impact on dry matter accumulation and tuber yield, showing no significant difference from control treatments. However, water deficit during the tuber initiation stage can inhibit plant growth and significantly reduce yield. Excessive water supply is not conducive to yield or quality improvement, whereas proper water regulation can enhance both. Mild water stress during starch accumulation has been found to increase marketable yield and improve the accumulation of proteins and reducing sugars in tubers. Therefore, appropriate water regulation strategies are essential to promote dry matter accumulation and improve potato yield and quality.

4. Conclusion

Water stress directly impacts the growth and development, photosynthetic characteristics, yield, and quality of potato plants. Proper water management can improve water use efficiency and promote both yield and quality. Extensive studies have shown that water stress inhibits root length, plant height, stem thickness, and leaf area, with varying effects depending on the growth stage. Reasonable water stress during the seedling period

can enhance drought resistance and promote plant growth. However, during tuber formation, water stress reduces yield. Exposure to water stress elevates reactive oxygen species (ROS) and malondialdehyde (MDA) content, inhibiting plant growth. To mitigate this, plants regulate osmotic substances such as proteins, soluble sugars, and proline to resist damage from water stress. However, some researchers have argued that there is no direct correlation between free proline and drought resistance in crops, indicating that further studies are needed to clarify the relationship. Additionally, there is a lack of studies examining gene expression and regulation under varying water stress levels from a molecular perspective. Future research should focus on gene localization, molecular marker breeding, and other biotechnological approaches to enhance the drought resistance and water use efficiency of potatoes, fostering the sustainable development of the potato industry.

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