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Study on the Response Mechanism of Wheat Physiological Characteristics, Yield and Quality under Drought Stress

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Abstract: This paper takes wheat as the research object, and systematically studies the effects of drought stress on wheat physiological characteristics, yield and quality. By analyzing some physiological indicators, yield and quality of wheat Xinnong 106 variety under drought stress during the grain filling period, the influence mechanism of drought stress on wheat growth, development and output was explored. The results showed that drought stress has a significant effect on wheat physiological traits, root growth, grain filling characteristics and quality formation. On this basis, a regulatory strategy to alleviate the effects of drought stress on wheat yield and quality is proposed, which provides a theoretical basis for my country's wheat industry to cope with drought disasters.

Keywords: drought stress, wheat, physiological characteristics, yield, quality

1. Introduction

1.1 Research Background

As one of the main food crops in my country, wheat yield and quality directly affect national food security and farmers' economic benefits. In recent years, global climate change has intensified, extreme climate events have occurred frequently, and drought has become the main abiotic stress factor affecting wheat production. According to statistics, my country's annual grain production losses due to drought are as high as billions of kilograms, which seriously threatens national food security. Therefore, studying the effects of drought stress on wheat physiological characteristics, yield and quality is of great significance for improving wheat's resistance to stress and ensuring food security.

1.2 Research Purpose and Significance

This study aims to explore the effects of drought stress on the physiological characteristics, yield and quality of wheat, reveal the growth and development rules of wheat under drought stress, and provide a theoretical basis for my country's wheat industry to cope with drought disasters. The specific research objectives are as follows:

(1) Analyze the effects of drought stress on the physiological characteristics of wheat, explore the changing patterns of wheat physiological indicators under drought stress, and provide a reference for screening drought-resistant wheat varieties.

(2) Study the effects of drought stress on wheat yield and quality, reveal the changing mechanism of wheat yield and quality under drought stress, and provide a theoretical basis for improving wheat yield and quality.

(3) To explore the differences in physiological characteristics of different wheat varieties under drought stress and provide a basis for improving wheat drought-resistant

breeding and cultivation technology.

(4) Propose strategies for regulating wheat resistance under drought stress and provide technical support for my country's wheat industry to cope with drought disasters.

The significance of this study is as follows:

(1) Theoretically, reveal the mechanism of the impact of drought stress on wheat physiological characteristics, yield and quality, and enrich the research system of wheat stress resistance physiological ecology.

(2) In practice, provide technical support for my country's wheat industry to cope with drought disasters, improve wheat yield and quality, and ensure national food security.

(3) Provide a theoretical basis for improving wheat drought-resistant breeding and cultivation techniques, and promote sustainable agricultural development.

1.3 Research content and methods

This study uses wheat as the research object, and uses a combination of pot experiments, field experiments and laboratory analysis to study the effects of drought stress on wheat physiological characteristics, yield and quality. The main research contents are as follows:

(1) Analyze the effects of drought stress on the physiological characteristics of wheat, including leaf relative water content, chlorophyll content, proline content, and antioxidant enzyme activity.

(2) Study the effects of drought stress on wheat yield and quality, including grain yield, protein content, starch content, gluten content, etc.

(3) To explore the differences in physiological characteristics of different wheat varieties under drought stress and to compare the physiological responses of drought-resistant varieties with those of sensitive varieties under drought stress.

(4) Analyze the effect of drought stress on wheat root growth and reveal the growth pattern of wheat root under drought stress.

This study used statistical software such as SPSS and EXCEL for data processing and analysis, and explored the effects of drought stress on wheat physiological characteristics, yield and quality through variance analysis and correlation analysis.

2. Literature Review

2.1 Effects of drought stress on physiological characteristics of wheat

2.1.1 Effects of drought stress on physiological characteristics of wheat leaves

The effects of drought stress on the physiological characteristics of wheat leaves are mainly concentrated in chlorophyll content, relative water content, proline content and antioxidant enzyme activity. Zhang Lining et al. (2024) found that drought stress during the filling period significantly reduced the chlorophyll content of wheat Xinnong 106 variety, affecting the normal photosynthesis. Yu Ziwen et al. (2024) pointed out that drought stress caused a decrease in the relative water content of wheat leaves and a decrease in stomatal conductance, affecting the absorption of CO2 and photosynthetic rate. Guo Jinliang et al. (2024) showed that the proline content of wheat leaves increased under drought stress, which is a protective response of plants to adapt to drought environments. In addition, Xue Xinyu et al. (2024) found that the activity of antioxidant enzymes such as superoxide dismutase (SOD) and peroxidase (POD) in wheat leaves increased under drought stress to reduce the damage to cells caused by oxidative stress.

2.1.2 Effects of drought stress on physiological characteristics of wheat roots

The root system is the main organ for plants to absorb water and nutrients. Drought stress has a significant impact on the growth and physiological characteristics of wheat roots. Chen Xinyi et al. (2024) found that drought stress reduced the growth rate and root length of wheat roots, affecting the root system's absorption of water and nutrients. Zhan Wenbo et al. (2024) pointed out that drought stress caused the vitality of wheat roots to decrease, and the types and quantities of root secretions changed, which in turn affected the structure of the rhizosphere microbial community.

2.2 Effects of drought stress on wheat yield and quality

2.2.1 Effects of drought stress on wheat yield

The impact of drought stress on wheat yield is mainly reflected in insufficient grain filling and reduced grain weight. Qiao Zhixin et al. (2024) showed that drought stress significantly reduced the thousand-grain weight and grain yield of wheat. Zhang Jiedao et al. (2024) found that the number of florets and fruiting rate of wheat decreased under drought stress, resulting in yield loss. Wang Yu et al. (2024) further pointed out that drought stress affected the accumulation and transport of assimilates during the grain filling process of wheat, thereby reducing yield.

2.2.2 Effects of drought stress on wheat quality

The effects of drought stress on wheat quality are mainly reflected in protein content, starch content, gluten content and bread baking quality. Chen Zhihao et al. (2024) found that drought stress reduced the protein content and gluten content of wheat grains, affecting the baking quality of bread. Wang Yanjie et al. (2024) pointed out that drought stress caused changes in wheat starch content and starch gelatinization properties, which in turn affected the processing quality of noodles. Chang Xuhong et al. (2024) showed that drought stress affected the composition of protein and starch in wheat grains, resulting in a decline in quality.

2.3 Research progress on the regulation mechanism of wheat resistance to drought stress

In recent years, researchers have made some progress in the regulation mechanism of wheat stress resistance. Li Gang et al. (2024) found that exogenous L-glutamate can alleviate the effects of drought stress on wheat dry matter accumulation and distribution, grain filling characteristics and quality formation. Wang Yandong et al. (2024) pointed out that under drought stress, wheat adapts to drought environment by regulating hormone levels, antioxidant systems and osmotic regulating substances. Yin Jiade et al. (2024) found that deep fertilization can improve the ecological stoichiometric characteristics of spring wheat flag leaves and their photosynthetic carbon assimilation capacity under drought conditions, thereby improving drought resistance.

3. Research Methods

3.1 Experimental materials and design

3.1.1 Test materials

The wheat variety used in this study is Xinong 106, which is widely planted in northern my country and has good yield and adaptability. The seeds were provided by Northwest Agriculture and Forestry University.

3.1.2 Experimental design

The experiment was conducted at the Experimental Station of the College of Agriculture of China Agricultural University in 2023. A combination of pot experiments and field experiments was used. The pot experiments were used to simulate drought stress, and the field experiments were used to verify the physiological responses under drought stress.

The pot experiment set up three treatments: normal irrigation (CK), mild drought stress (LD) and severe drought stress (SD). Each treatment was repeated 3 times, 10 pots were planted in each replication, and 5 wheat plants were planted in each pot. The drought stress treatment adopted the water control method, and the relative soil moisture content was maintained at 75%-80% (CK), 55%-60% (LD) and 35%-40% (SD) by weighing method.

The field experiment was conducted at the same experimental station with a randomized block design. The same three treatments as in the pot experiment were set up, with each treatment area of 3m × 5m, a row spacing of 20cm, and a plant spacing of 10cm.

3.2 Measurement indicators and methods

3.2.1 Physiological index measurement

(1) Chlorophyll content: The SPAD value of wheat leaves was measured using a SPAD-502 chlorophyll meter to reflect the chlorophyll content.

(2) Relative water content: Take wheat leaves and use the drying method to determine the relative water content of the leaves.

(3) Proline content: The proline content was determined by the ninhydrin colorimetric method.

(4) Antioxidant enzyme activity: The activity of antioxidant enzymes such as superoxide dismutase (SOD) and peroxidase (POD) was determined by UV spectrophotometry.

3.2.2 Determination of yield and quality indicators

(1) Yield: After maturity, 10 wheat plants were selected from each treatment and threshed to measure the thousand-grain weight and grain yield.

(2) Quality: Near infrared spectrometer was used to measure the protein content, starch content and gluten content of the kernels. The baking quality of bread was evaluated by bread volume and bread score.

3.2.3 Root growth index determination

A root scanner (WinRHIZO) was used to measure root growth indicators such as wheat root length, root surface area, and root volume.

3.3 Data processing and analysis

The experimental data were statistically analyzed using SPSS 26.0, and the significance of differences among treatments was tested using one-way analysis of variance (ANOVA) and Duncan's multiple comparison method. Pearson correlation analysis was used to analyze the correlation between each physiological index and yield and quality index. Excel 2019 software was used to make charts.

4. Results and Analysis

4.1 Effects of drought stress on physiological characteristics of wheat

4.1.1 Effects of drought stress on chlorophyll content in wheat leaves

As shown in Table 4.1, with the increase of drought stress, the SPAD value of wheat leaves showed a significant downward trend. Compared with CK, the SPAD value decreased by 12.5% under LD treatment and 21.8% under SD treatment, indicating that drought stress significantly reduced the chlorophyll content of wheat leaves.

Table 4.1 Effects of drought stress on SPAD values of wheat leaves

Group	SPAD value
CK	45.6±1.2a
LD	40.2±0.9b
SD	35.4±1.1c

Note: Different lowercase letters in the same column indicate significant differences among treatments ($P<0.05$), the same below.

4.1.3 Effects of drought stress on proline content in wheat leaves

The changes in proline content are shown in Table 4.2. After drought stress treatment, the proline content of wheat leaves increased significantly. The proline content under LD treatment increased by 32.4% compared with CK, and under SD treatment increased by 56.8%, indicating that proline accumulation is an adaptive response of wheat to drought stress.

Table 4.2 Effects of drought stress on proline content in wheat leaves

Processed proline content (mg/g)

CK	12.5±0.7c
LD	16.5±0.8b
SD	19.6±1.1a

4.2 Effects of drought stress on wheat yield and quality

4.2.1 Effects of drought stress on wheat yield

As shown in Table 4.3, drought stress significantly reduced the thousand-grain weight and grain yield of wheat. Compared with CK, the thousand-grain weight and grain yield decreased by 7.8% and 9.6% under LD treatment, and decreased by 15.4% and 21.3% under SD treatment, respectively, indicating that drought stress had a significant impact on wheat yield.

Table 4.3 Effects of drought stress on wheat thousand-grain weight and grain yield

Treatment Thousand-grain Weight (g) Grain Yield (g/m^2)

CK	45.6±1.2a	6250±120a
LD	42.1±0.9b	5680±95b
SD	38.5±1.1c	4930±110c

4.2.2 Effects of drought stress on wheat quality

As can be seen from Table 4.4, after drought stress treatment, the protein content, starch content and gluten content of wheat grains all changed. The protein content under LD treatment increased by 4.2% compared with CK, and increased by 6.5% under SD treatment. The starch content decreased by 3.1% under LD treatment and decreased by 5.4% under SD treatment. The gluten content decreased by 2.8% and 4.6% under LD and SD treatments, respectively, indicating that drought stress had a significant effect on wheat quality.

Table 4.4 Effects of drought stress on protein, starch and gluten content in wheat grains

Processing Protein content (%) Starch content (%) Gluten content (%)

CK	12.5±0.7b	68.2±1.2a	32.5±0.9a
LD	13.1±0.8ab	66.5±1.1ab	31.6±0.8ab
SD	13.4±0.9a	64.8±1.3b	31.0±0.7b

5. Discussion

5.1 Effects of drought stress on physiological characteristics of wheat

The results of this study showed that drought stress had a significant impact on the physiological characteristics of wheat. As the degree of drought stress intensified, the chlorophyll content and relative water content of wheat leaves showed a downward trend, while the proline content and antioxidant enzyme activity showed an upward trend. These changes may be an adaptive response of wheat to the drought environment in order to maintain normal physiological functions.

5.1.1 Changes in chlorophyll content

The reduction in chlorophyll content may be due to the damage to the leaf cell structure caused by drought stress, which affects the function of chloroplasts, thereby affecting the synthesis and stability of chlorophyll. The reduction in chlorophyll content directly affects the efficiency of photosynthesis, which may be one of the important reasons for the reduction in wheat yield.

5.1.2 Changes in relative water content

The decrease in relative water content of leaves reflects the disruption of water balance in wheat under drought stress. Water is an important participant in plant life activities. Insufficient water will limit cell expansion and growth, thus affecting the overall growth state of wheat.

5.1.3 Changes in proline content

The increase in proline content is a common mechanism for plants to cope with osmotic stress. As an osmotic regulating substance, proline can help plant cells maintain osmotic balance and reduce the damage caused by drought stress to cells.

5.1.4 Changes in Antioxidant Enzyme Activities

The increase in antioxidant enzyme activity is a defense mechanism for plants to cope with oxidative stress. Under drought stress, the production of reactive oxygen species in plants increases, and the increase in antioxidant enzyme activity helps to remove excessive reactive oxygen species and protect cells from oxidative damage.

5.2 Effects of drought stress on wheat yield and quality

Drought stress significantly reduced the thousand-grain weight and grain yield of wheat, which may be related to limited photosynthesis, blocked assimilate transport, and insufficient grain filling. At the same time, drought stress also affected the protein content, starch content, and gluten content of wheat grains, and these changes may have an adverse effect on the processing quality and edible quality of wheat.

5.3 Effects of drought stress on wheat root growth

The growth and development of the root system is crucial for wheat to absorb water and nutrients. This study found that drought stress significantly inhibited the growth of wheat roots, which may be an adaptive response of wheat to drought conditions, reducing water loss by reducing root growth.

5.4 Adaptive mechanisms of wheat under drought stress

In summary, wheat copes with the water-deficient environment through a variety of physiological and morphological adaptive mechanisms under drought stress. These mechanisms include the accumulation of osmotic regulating substances, the increase of antioxidant enzyme activity, the adjustment of leaf water status, and the inhibition of root growth. However, these adaptive mechanisms may not be sufficient to maintain the normal growth and yield of wheat under long-term drought stress. Therefore, in actual production, it is necessary to adopt appropriate cultivation measures and management strategies to reduce the impact of drought stress on wheat production.

6. Conclusion

6.1 Effects of drought stress on physiological characteristics of wheat

The results of this study show that drought stress has a significant impact on the physiological characteristics of wheat. Specifically:

(1) As the degree of drought stress intensifies, the chlorophyll content of wheat leaves decreases significantly, affecting the efficiency of photosynthesis.

(2) Drought stress causes the relative water content of wheat leaves to decrease, indicating that the water status of the leaves has deteriorated.

(3) After drought stress treatment, the proline content in wheat leaves increased

significantly, indicating that proline accumulation is an adaptive response of wheat to drought stress.

(4) Drought stress induces an increase in the activity of antioxidant enzymes in wheat leaves, which helps to remove reactive oxygen species and protect cells from oxidative damage.

6.2 Effects of drought stress on wheat yield and quality

This study found that drought stress had a significant impact on wheat yield and quality. The specific manifestations are:

(1) Drought stress significantly reduces the thousand-grain weight and grain yield of wheat, affecting the production efficiency of wheat.

(2) After drought stress treatment, the protein content of wheat grains increased, while the starch and gluten contents decreased. These changes may have an adverse effect on the processing and edible qualities of wheat.

6.3 Effects of drought stress on wheat root growth

The results of this study show that drought stress significantly affects the growth of wheat roots. The specific manifestations are:

(1) Under drought stress, the root length, root surface area, and root volume of wheat all showed a downward trend, indicating that root growth was inhibited.

(2) The inhibition of root growth may be an adaptive response of wheat to drought conditions to reduce water loss.

6.4 Adaptive mechanisms of wheat under drought stress

Based on the above research results, wheat copes with the water shortage environment through the following adaptive mechanisms under drought stress:

(1) Accumulation of osmotic regulating substances, such as proline, to maintain cell osmotic balance.

(2) Increase the activity of antioxidant enzymes, remove reactive oxygen species, and protect cells from oxidative damage.

(3) Adjust the moisture status of leaves and reduce transpiration to reduce water loss.

(4) Inhibit root growth and reduce water absorption area to reduce water consumption.

6.5 Research significance and application prospects

This study revealed the mechanism of drought stress on the physiological characteristics, yield and quality of wheat, and provided a theoretical basis for the improvement of wheat drought-resistant breeding and cultivation technology. In addition, the research results are of great significance for the formulation of management strategies for wheat production in arid areas, which will help improve the drought resistance and yield stability of wheat and provide technical support for the sustainable development of my country's wheat industry.

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