

Physiological Characteristics of Soybean Varieties Under Meadow-Alluvial and Water-Deficit Soil Conditions of The Bukhara Region

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Abstract

This article presents experimental data on the physiological indicators that determine stress tolerance in soybean varieties under varying soil moisture regimes (optimal, limited, and arid/drought). The study reveals that changes in these physiological parameters are significantly influenced by soil moisture levels, plant developmental stages, and the unique biological characteristics of each variety. Specifically, the dynamics of cellular turgidity, water-binding capacity, and catalase enzyme activity were analyzed to evaluate the adaptive mechanisms of soybeans under water-deficit conditions. The findings provide insights into selecting resilient cultivars for cultivation in the meadow-alluvial soils of the Bukhara region.

Keywords: Soybean plant, stress, soil moisture levels, turgidity, bound water, catalase enzyme.

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1. Introduction

Soybean cultivation is widespread globally, recognized as a primary staple due to its exceptional nutritional value. Despite significant advancements in production, environmental stress continues to pose a persistent threat to soybean yields [1].

Drought stands as one of the most critical abiotic stresses affecting crop productivity worldwide. Drought stress induces water deficits in plants, leading to cellular dehydration and the disruption of normal cellular functions. This can result in severe consequences,

including reduced growth rates, diminished leaf area, lowered water potential, decreased photosynthetic intensity, slower assimilate transport, and, in extreme cases, plant mortality [2,3].

In the foreseeable future, increasing water scarcity may further limit water availability for agricultural purposes. Consequently, investigating drought-tolerance mechanisms in soybean plants offers a more reliable strategy for sustainable production. Specific soybean genotypes can prevent or delay tissue dehydration when facing drought through adaptive traits such as early stomatal closure, reduced transpiration rates under high

vapor pressure deficits, and deeper root systems characterized by a higher proportion of lateral and expansive roots [4,5].

The necessity of increasing soybean yields is driven by national and regional food security requirements, aiming to meet nutritional demands while minimizing environmental impact. Soybean proteins and amino acids are essential, providing high-quality nutrition for both humans and livestock. Furthermore, soybean oil contains beneficial unsaturated fatty acids, vitamins, minerals, and other bioactive compounds advantageous to human and animal health [6].

Soybean crops are subjected to numerous unfavorable environmental conditions, among which drought stress causes the most substantial yield losses. Research indicates that increasing crop productivity may be approaching a ceiling due to stress factors, as evidenced by the stabilization of theoretical yield potential at approximately 80% in recent years. These stress factors, whether biotic or abiotic, significantly impair plant growth and development. Among abiotic factors, drought is considered the most devastating, affecting all stages of plant ontogeny and leading to massive losses in soybean production. In field conditions, such stresses often occur simultaneously, restricting plant development and undermining sustainable agriculture [7].

Drought stress triggers alterations in photosynthesis, respiration, and other physiological processes, which can deplete the plant's energy reserves and stunt growth. Limited water supply leads to plant dehydration, a decline in leaf water content, and the loss of leaf turgor, ultimately resulting in stomatal closure [8].

Water deficit stress negatively impacts plant morphology as well as physiological and biochemical parameters, thereby reducing soybean yields. Drought has been shown to decrease both water content and chlorophyll levels in leaves. Simultaneously, water deficit stress increases the concentration of proline and malondialdehyde (MDA) in soybean leaves. Drought tolerance in soybeans is closely associated with higher water and proline content, significantly lower MDA levels, and reduced chlorophyll degradation. Furthermore, stress tolerance in soybeans is linked to high osmotic adjustment through the accumulation of amino acids, sugars, and proline, alongside higher photosynthetic efficiency [9].

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2. Methods

Research Objects and Experimental Design. The research focused on several soybean varieties currently cultivated across extensive areas in Uzbekistan, namely: Zara, Chara, Bars, Arisoy, Optima, Zamin, and Olmos. The study aimed to evaluate the impact of varying soil moisture levels on these varieties, focusing on physiological indicators of drought tolerance and productivity.

The experiments were conducted under controlled soil moisture regimes, maintained at levels no less than 70%, 50%, and 30% of the field capacity (FC). All experimental plots were arranged using a randomized block design with three replications. Soil samples for agrochemical analysis were collected from depths of 0–50 cm in triplicate. These samples were analyzed under laboratory conditions according to generally accepted standard protocols.

Physiological Assessments. Physiological and phenological observations were carried out during the budding, flowering, and pod-formation stages of the soybean varieties. For all measurements, the 3rd and 4th well-developed leaves from the upper part of the stem were sampled. Ten individual plants from each variety were selected to determine specific parameters. The following physiological indicators were measured:

- Leaf Cell Turgidity: Determined using a turgorometer (model TN-10-60Ts, manufactured in Moldova) [10].
- Bound Water Content: Measured using the refractometer and thermostat method [11].
- Catalase Enzyme Activity: Determined via the gasometric method by measuring the volume of oxygen released during the reaction [11].

Data Collection and Analysis. All observations, measurements, and research procedures concerning plant growth and development were executed following established methodologies. The experimental work was conducted with four biological replications and three analytical replications to ensure statistical reliability.

3. Results and Discussion

Leaf Turgidity Dynamics. Turgor capacity is one of the most sensitive physiological indicators reflecting the water status of leaves; its rate of decline serves as a critical criterion for evaluating a variety's drought tolerance. Phase-specific analysis revealed that across all varieties, turgor levels were lowest during the budding stage, moderate during flowering, and reached their peak during the pod-formation stage. This is a physiologically natural phenomenon associated with active water consumption during the formation of reproductive organs and a subsequent increase in intracellular pressure. The high turgor levels observed during pod formation suggest an intensified accumulation of osmotic substances in the leaves, which helps maintain cellular pressure.

Regarding soil moisture levels, the highest turgor levels across all varieties were recorded at 70% moisture. At 50% moisture, these indicators showed a moderate decline, while at 30% moisture, a sharp reduction in turgor was observed in all varieties. This indicates that under severe water deficit, leaf cells lack sufficient water to maintain osmotic equilibrium. Comparative analysis among varieties showed that Arisoy, Zamin, and Chara maintained relatively stable turgor levels, whereas Zara, Olmos, and Bars experienced a more rapid decline under low moisture conditions. In the Optima variety, the decline was also evident, though it trended toward the intermediate group. During pod formation, the highest turgor was observed in Arisoy, Zamin, and Chara, indicating their ability to sustain internal cellular pressure under drought. Conversely, the lowest values at 30% moisture were recorded in Zara, Bars, and Optima, highlighting their sensitivity to severe drought.

Bound Water Content and Adaptive Mechanisms. A consistent pattern emerged across all varieties: as soil moisture decreases, the proportion of bound water in the leaves increases. This is explained by the plants' attempt to retain water within internal molecular bonds to maintain osmotic pressure, stabilize cellular structures, and prevent metabolic disruption under drought.

In terms of developmental phases, bound water content was lowest at budding, moderate at flowering, and highest during pod formation. The increased demand for water and the intensification of physiological processes during pod formation led to a greater accumulation of bound water. Notable varietal differences were observed: Arisoy, Zamin, and Chara exhibited higher bound water indicators, distinguishing them as drought-tolerant. While Zara and Optima showed lower values, they

maintained stable growth as moisture decreased. Bars and Olmos demonstrated moderate adaptability. At 70% moisture, water binding was minimal; it increased at 50% and reached maximum levels at 30% moisture across all varieties, signifying the full activation of plant defense mechanisms. The stability of this increase during pod formation—the most critical stage of the plant life cycle—enhances overall stress tolerance. These results confirm that increasing bound water content is a primary adaptive mechanism for survival and continued development under drought.

Catalase Enzyme Activity and Oxidative Stress Management. Overall, a decrease in soil moisture triggered an increase in catalase enzyme activity across all varieties. This indicates the activation of enzymatic defense mechanisms to mitigate oxidative stress induced by drought.

The highest catalase activity under reduced moisture was observed in the Arisoy and Zamin varieties, reflecting their superior adaptation and robust defense systems. In Zara and Optima, these changes were less pronounced, suggesting higher sensitivity to drought. Chara, Olmos, and Bars showed an intermediate response. Given that the flowering stage is a vital physiological period, the dynamics of catalase activity at this stage are crucial for comparing stress tolerance levels.

Under favorable conditions (70% moisture), catalase levels were at their lowest due to minimal oxidative stress. At 50% moisture, enzyme activity increased moderately as adaptation mechanisms were engaged. At the minimum moisture level of 30%, catalase activity reached its peak, indicating the defense system was operating at maximum capacity. Varieties like Arisoy, Zamin, and partially Chara stood out with the most active responses. In contrast, Optima and Zara appeared more vulnerable due to their lower rate of catalase induction. These findings provide essential data for breeding programs and for developing planting strategies in regions with limited water resources.

4. Conclusions

The scientific results obtained from this research demonstrate that the intensity of physiological and tolerance indicators in soybean varieties fluctuates significantly depending on the severity of soil drought. Among the drought-tolerant varieties—Arisoy, Zamin, and Chara—there was a marked increase in leaf turgidity, bound water content, and catalase enzyme activity,

alongside enhanced photosynthetic intensity. In contrast, the moderately tolerant varieties (Olmos and Bars) and the sensitive varieties (Optima and Zara) exhibited a decline in these key physiological parameters under water-stress conditions.

Based on these findings, practical recommendations have been developed for the strategic cultivation of soybean varieties in the water-scarce conditions of the Bukhara region to ensure high agricultural productivity. Optimal soil moisture thresholds that guarantee maximum grain yield were identified for each variety, providing a scientific basis for yield optimization. The study successfully categorized the evaluated varieties into three distinct groups based on their adaptive capacity: tolerant, moderately tolerant, and sensitive. These classifications offer critical insights for future breeding programs and provide a framework for establishing planting strategies in regions with limited water resources.

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