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EFFECT OF POTASSIUM FERTILIZATION ON PHYSIOLOGYCAL, GROWTH, PHENOLOGY PERFORMANCE OF MUNG BEAN UNDER LOW WATER AVAILABILITY

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ABSTRACT

Mung bean (*Vigna radiata* L.) is an important legume crop that plays a strategic role as a source of plant-based protein, a functional food ingredient, and an adaptive crop widely cultivated in various tropical and subtropical regions. Mung bean are a legume crop with high agronomic potential, mung bean productivity still faces several challenges, particularly due to climate change and rainfall patterns. These environmental changes can reduce water availability in agricultural lands and increase the risk of drought stress. Low water availability is one of the primary limiting factors in mung bean cultivation because it impedes overall plant performance, such as growth, phenological development, and physiological functions. Water deficit can disrupt plant biological processes through reduced tissue water status, impaired nutrient uptake and distribution, decreased metabolic activity, and increased oxidative stress, which eventually leads to reduced productivity. Under drought stress conditions, potassium (K) plays a crucial role as an essential nutrient that helps improve plant tolerance to water limitations. Potassium contributes to maintaining osmotic balance, improve water use efficiency, support physiological stability, and strengthening plant adaptation mechanisms against drought stress. Therefore, proper potassium management can be a potential strategy to improve mungbean resilience and maintain plant performance under low water availability conditions.

Key words: Drought stress, Mung bean, Potassium Fertilization

INTRODUCTION

Mung bean (*Vigna radiata* L.) are one of the most important legume crops in the world, particularly in tropical and subtropical regions, thanks to their high protein content (20–30%), good digestibility, and complete amino acid profile (Huang *et al*., 2024). This crop has unique agronomic characteristics, such as a relatively short growing season (55–70 days) and the ability to fix nitrogen through symbiosis, which can improve soil fertility for subsequent crops in a rotation system (Diatta *et al*., 2020; Pataczek *et al*., 2018). Mung bean exhibit broad adaptability, yet their productivity remains low, partly due to their susceptibility to low water availability during critical growth phases (Singh *et al*., 2021). Climate change, characterized by rising global temperatures and extreme weather events including more frequent and intense droughts directly impacts water availability for agriculture (Mehta, 2024)

The productivity of this crop is increasingly threatened by climate change, which leads to reduced rainfall and low soil moisture availability across various growing regions. Low water availability causes plants to experience drought stress, which disrupts basic physiological mechanisms, inhibits physical growth, and disrupts the plant life cycle (Chaudhary *et al*., 2022). The main challenge in growing mung bean in dryland conditions is maintaining plant metabolic stability to ensure productivity despite severe water stress. Potassium, as an essential macronutrient, plays a multifaceted role in enhancing plant tolerance to drought (Liaqat *et al*., 2022). Potassium is known as the primary osmotic regulator responsible for cell turgor, enzyme activation, and water-use efficiency through stomatal control, osmotic adjustment, and enzyme activation not only support normal metabolic functions but also provide structural support that strengthens the plant’s ability to maintain productivity under drought conditions precise mechanisms that help plants sustain basic metabolic processes such as photosynthesis and protein synthesis even under environmental stress. (Hasanuzzaman *et al*., 2018; Saha *et al*., 2025)

RESULTS AND DISCUSSION

Water availabilty and the role of potassium fertilizer

Soil water availability directly determines plant water status; as soil moisture levels drop to the point of water deficit, this illustrates how limited water availability leading to drought in a region reduces leaf water potential and fundamentally disrupts plant physiological processes (Turner, 2019). Plants experiencing drought stress due to water limitations will suffer systemic disruptions in their growth and development.

Under such stress conditions, Potassium (K) is recognized as an essential macronutrient that plays a critical role in enhancing plant tolerance to drought stress through osmotic regulation, water-use efficiency, and cellular metabolic stability (Pamungkas *et al*., 2022; Hasanuzzaman *et al*., 2018). Potassium plays a multifaceted role in plant physiology, being involved in the activation of over 60 enzymes, protein synthesis, photosynthesis, sugar translocation, and most importantly, the regulation of cell turgor through the opening and closing of stomata (Islam *et al*., 2024; Kumar *et al*., 2020).

Plant physiological

a) Physiological disorders under water stress

Physiologically, drought stress caused by low water availability leads to serious disruptions in cell stability and metabolic function. This is the starting point where systemic damage begins (Singh *et al*., 2021). Drought triggers excessive accumulation of Reactive Oxygen Species (ROS), which aggressively attack membrane lipids through peroxidation (Lian *et al*., 2023). This damage leads to increased membrane permeability, manifesting as increased electrolyte leakage, indicating that internal ions are exiting the cell and cellular stability has been lost (Islam *et al*., 2021). Prolonged water stress triggers the degradation of chlorophyll or photosynthetic pigments due to oxidative stress (Zahra *et al*., 2023). This decrease in chlorophyll levels visually lowers the Chlorophyll Index or SPAD value; a decrease in the SPAD value significantly reduces the plant's ability to absorb light. (Umar *et al*., 2019: Singh *et al*., 2021). Stomatal closure is an immediate defensive response by plants to reduce water loss through transpiration caused by drought. However, this also limits CO_2 uptake, thereby reducing the rate of photosynthesis and energy production (Islam *et al*., 2024).

b) Potassium role mitigating physiological disturbance

Potassium acts as a primary protector by enhancing the activity of the antioxidant enzyme NADPH oxidase, which is the main source of ROS. With reduced ROS levels, lipid peroxidation in the cell membrane decreases. Potassium helps maintain the stability of the phospholipid bilayer, thereby preventing internal ions from leaking out randomly, preserving membrane integrity (reducing electrolyte leakage) even under conditions of low water availability. (Houmani *et al*., 2022). Potassium acts as an antioxidant to ensure chlorophyll levels remain stable, thereby protecting chlorophyll from oxidative degradation (Ahmad *et al*., 2019). Potassium also activates the ATP synthase enzyme required for processing light energy, ensuring the plant retains its green color and strong photosynthetic capacity. Thus, the plant's photosynthetic capacity is maintained to support energy needs during periods of stress (Ghassemi *et al*., 2018;). Potassium plays a direct role in the mechanism of stomatal opening and closing through the precise regulation of K^+ ion kinetics in guard cells to prevent dehydration (Ahmad *et al*., 2025). Conversely, under mild stress conditions, K^+ helps keep stomata open efficiently to maintain maximum CO_2 uptake with minimal water loss. This allows plants to optimize the balance between water conservation and CO_2 uptake to maintain metabolic functionality (Islam *et al*., 2021)

Growth dynamics: physical manifestations of physiological disturbances

a) Physical growth inhibition under water stress

Failure at the physiological level due to drought stress automatically inhibits the plant's physical expansion. Growth is the result of energy availability and cell turgor generated at the physiological stage. A decrease in soil water availability directly results in reduced cell turgor pressure, which inhibits cell division and elongation, thereby stunting plant height (Anjum *et al*., 2017). Drought causes a decrease in photosynthetic product (energy) production due to stomatal closure, leading to conditions in which total plant biomass accumulation decreases significantly (Qiao *et al*., 2024). This reduction is exacerbated by impaired nutrient uptake due to halted mass flow in the soil caused by low water availability (Islam *et al*., 2024). Potassium enhances water use efficiency, activates the sucrose synthase enzyme, and facilitates sugar loading into the phloem. Under drought conditions, plants tend to allocate more biomass to roots to seek water, thereby reducing the root-to-shoot ratio. Severe stress triggers stunted root growth due to energy limitations (Waleed & Anwar, 2025).

b) Role of potassium role in maintaining growth characteristics

Potassium acts as an osmotic solute by increasing cellular osmotic pressure through the draw of water into the cell. High K+ concentrations within the cell create an osmotic pressure that draws water in, maintaining high turgor pressure. This allows cells to remain stretched and divide, ensuring cell elongation continues so that plants do not become stunted even when water availability is low (Saha *et al*., 2025; Rafeeq *et al*., 2025). Potassium accelerates the transport of photosynthetic products from the leaves to storage organs to prevent sugar accumulation in the leaves which can damage chlorophyll and ensures biomass remains evenly distributed, helping to maintain plant dry weight (Sardans & Peñuelas, 2021). Potassium stimulates signals to elongate deeper lateral roots; plants allocate more energy to strengthen the root system to absorb water more effectively from residual soil moisture, thereby providing a foundation for the plant to maintain shoot growth (Kumar *et al*., 2020; Rani Saha *et al*., 2025).

Phenological plasticity: life cycle adaptations to energy stress

a) Development timing shift due to under low water availability

Growth constraints and chronic energy deficits force plants to make significant modifications to their phenological stages as a last-resort survival strategy. The development of the third leaf (trifoliate) is hindered due to low turgor pressure and limited energy supply from photosynthesis, which has been disrupted from the outset (Hanif & Wahid, 2018). Drought triggers a surge in abscisic acid (ABA), which acts as a flowering inhibitor, forcing plants into a “quiescence” strategy or reproductive delay (Singh *et al*., 2021). This condition physically slows down flower bud development (Van Haeften *et al*., 2023). The most severe consequence of drought is “carbon starvation,” where plants no longer have sufficient sugars to support flowers. A decrease in auxin in the abscission zone makes cells sensitive to ethylene, which triggers the IDA (Inflorescence Deficient in Abscission) peptide to activate genes for hydrolytic enzymes such as cellulase and polygalacturonase (Chaudhary *et al*., 2022; Shanker *et al*., 2021). These enzymes dissolve the middle lamella of the flower stalk, causing the flower to eventually fall off.

b) Potassium optimization in maintaining life phase precision

Potassium ensures that tissue water status and protein synthesis remain stable during early leaf formation, thereby maintaining leaf cell differentiation and preventing delays in the vegetative phase that could permanently reduce production capacity (Amanullah *et al*., 2022). Potassium stabilizes this process by maintaining hormonal balance between auxin and cytokinin against ABA, preventing excessive ABA surges that could trigger flowering failure. Potassium ensures plants enter the generative phase with sufficient energy and that flower initiation occurs on time even under the threat of drought stress (Sardans & Peñuelas, 2021). Potassium plays a crucial role by facilitating sugar transport to the flower and suppressing hormonal abscission signals and the activation of hydrolytic enzymes (cellulases). Potassium prevents the dissolution of cell walls in the flower stalk, maintains a stable flow of nutrients (carbohydrates) to the flower, and eliminates the primary cause of abscission namely, “carbon starvation” ensuring that pods continue to form and harvest maturity remains stable even under conditions of low water availability. (Kouser *et al*., 2022).

Interaction

The interaction between low water availability which triggers water deficit and potassium fertilization in mung bean plants reveals a reciprocal relationship that determines the plants’ drought tolerance threshold. In the absence of potassium, extreme water stress would immediately damage cell wall integrity as indicated by a surge in electrolyte leakage leading to acute dehydration that would cause the mung bean plants to wilt and die (Rani Saha *et al*., 2025). An interaction occurs when potassium is applied to the soil and acts as a primary physiological buffer that retains water within cells, maintains stomatal density, and protects the leaf chlorophyll content index from damage (Vikanksha *et al*., 2025).

Under normal conditions, water limitation would halt cell division, causing the plants to become stunted, lose total biomass, and be forced to shut down their canopy tissues due to a disrupted energy supply. A positive interaction begins when potassium supply is optimized, as potassium reverses this downward trend by reorganizing the plant's growth direction through the regulation of root-shoot ratio, causing roots to grow deeper in search of residual water (Aizaz *et al*., 2023). Through the sufficient water successfully absorbed by the root system, potassium actively modifies the plant's internal osmotic potential, thereby securing the phenological timeline of mung beans; as a result, the timing of trifoliate leaf emergence, flowering, and harvest is not forced to occur prematurely (abnormally) as an emergency response in anticipation of death, but rather proceeds in a timely and normal manner (Islam *et al*., 2024).

CONCLUSION

1. Water stress is the primary limiting factor that disrupts cellular metabolism, leading to reproductive failure in mung bean.
2. Potassium acts as the primary protector by stabilizing cell membranes, preventing chlorophyll degradation, and maintaining stomatal function to optimize water use efficiency.
3. These improvements at the cellular level promote physical plant growth, as potassium maintains turgor pressure for cell elongation and stimulates deeper root development.
4. The physiological stability and growth promoted by potassium help prevent "carbon starvation" thereby preventing flower drop and premature ripening.
5. The interaction between water availability and potassium fertilizer demonstrates that potassium acts as a physiological buffer whose effectiveness actually increases as drought stress levels rise.
6. Optimizing potassium application rates is a crucial strategy for addressing water constraints, stabilizing the life cycle, and maintaining mung bean productivity amid the challenges of climate change.

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