REVIEW ARTICLE

Assessing The Influence of Phosphorus and Moisture Stress Dynamics on Mungbean: A Scientific Exploration

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DOI: 10.18811/ijpen.v11i01.04

Abstract

Mungbean (*Vigna radiata* L.) stands as an essential leguminous crop globally, particularly in regions like India, owing to its nutritional significance and wider adaptability. This review into the intricate dynamics among phosphorus (P) levels, an important nutrient for plant growth, and moisture stress, a common challenge in agriculture, on mungbean's morphological and biochemical aspects. Essential for plant growth, profoundly impacts mungbean's morphological characteristics and biochemical homes. Adequate phosphorus supply stimulates lateral root proliferation and elongation, improving root exploration for progressed nutrient and water uptake, thereby improving the plant's capability to face up to environmental stresses and nutrient deficiencies.

Under drought conditions, mungbean plants exhibit poor root growth, resulting in reduced nutrient and water use-efficiency. Moreover, moisture stress inhibits shoot growth and architectural development, resulting in stunted growth, reduced internode elongation, and diminished leaf expansion, ultimately leading to decreased light interception and photosynthetic activity. Additionally, the interaction between phosphorus levels and moisture stress significantly influences mungbean's responses, dictating adaptive strategies to varying environmental conditions. Conversely, phosphorus-enriched plants demonstrate enhanced resilience to moisture stress, maintaining root elongation and shoot development, even under water-limited conditions. This assessment underscores the significance of comprehensive nutrient management techniques in mitigating the detrimental influences of environmental fluctuations on mungbean cultivation, emphasizing the need for interdisciplinary research and innovative answers to decorate crop productiveness and sustainability in the face of global environmental challenges.

Highlights:

- Adequate phosphorus enhances mungbean root proliferation, shoot biomass and Reproductive structures leading to improved nutrient uptake and resilience to environmental stress.
- Moisture stress conditions reduce root elongation, shoot growth and Reproductive success in mung bean, limiting overall biomass and yield.
- Moisture stress leads to increase proline levels which help to maintain cell turgor and maintain oxidative damage.
- Sufficient phosphorus maintains better root and shoot development compared to deficient plants Under draught condition.

Keywords: Mungbean, Phosphorus level, moisture stress, root morphology, nutrient uptake, stress tolerance

International Journal of Plant and Environment (2025); **ISSN:** 2454-1117 (Print), 2455-202X (Online)

Introduction

Mungbean (*Vigna radiata* L.) stands as a cornerstone of agricultural systems worldwide, celebrated for its nutritional richness and adaptability, particularly in regions like India where it serves as a vital protein source and income generator for millions of farmers (Kumari *et al*., 2020). Phosphorus (P), plays a central role for in the belowground and aboveground growth and development of mungbean (Li *et al.,* 2017). Concurrently, moisture stress, exacerbated by climate variability, poses a formidable challenge to mungbean cultivation, especially in arid and semi-arid regions, where water scarcity is a pressing concern (Farooq *et al*., 2009).. The combined impact of phosphorus and moisture stress management can enhance the sustainability of mungbean cultivation in India.

Phosphorus is a fundamental nutrient for plant growth, playing a crucial role in various physiological processes, including energy storage and transfer, nucleic acid synthesis, and enzyme activation (Vance *et al.,* 2003). Adequate phosphorus supply stimulates root proliferation and elongation, enhancing nutrient and water uptake efficiency from the soil, thereby improving plant vigor and stress tolerance (Sun *et al.,* 2020). Additionally,

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How to cite this article: Pandey, S., Srivastava, P., Chauhan, A. S., Kumar, V., Singh, A. (2025). Assessing The Influence of Phosphorus and Moisture Stress Dynamics on Mungbean: A Scientific Exploration. International Journal of Plant and Environment. 11(1), 34-40.

Submitted: 24/07/2024 **Accepted:** 21/02/2025 **Published:** 28/03/2025

phosphorus influences shoot growth and architecture, promoting robust biomass accumulation, increased leaf area, and enhanced canopy development, which are essential for optimizing light interception and photosynthetic efficiency (Wang *et al.,* 2018). Moreover, phosphorus availability affects the development and morphology of reproductive structures, influencing flower production, pollen viability, and pod set and filling, ultimately impacting crop yield and quality. However, moisture stress poses significant challenges to munbean cultivation, disrupting plant water balance and physiological processes. Under drought conditions, mungbean plants experience reduced root elongation and lateral root proliferation, leading to decreased nutrient and water uptake efficiency (Ashraf and Harris, 2013). Furthermore, moisture stress inhibits shoot growth and architectural development, resulting in stunted growth, diminished leaf expansion, and compromised photosynthetic activity, thereby limiting biomass production and yield potential (Kumari *et al.,* 2020). Additionally, drought-induced water deficits often lead to flower abortion, reduced pollen viability, and impaired pod set and filling, resulting in yield losses and compromised seed quality, exacerbating food insecurity and economic hardships for farmers.

The interaction between phosphorus levels and moisture stress significantly influences mungbean's responses, dictating adaptive strategies to varying environmental conditions. Under optimal conditions, mungbean plants exhibit vigorous growth, robust root systems, and enhanced shoot development, promoting greater resilience to environmental stresses (Gao *et al.,* 2018). However, under moisture stress coupled with phosphorus deficiency, mungbean plants display reduced root and shoot growth, compromising crop productivity and resilience. Conversely, phosphorus-enriched plants demonstrate enhanced resilience to moisture stress, maintaining root elongation and shoot development, even under water-limited conditions.

This review underscores the importance of holistic nutrient management strategies in mitigating the adverse impacts of environmental fluctuations on mungbean cultivation, emphasizing the need for interdisciplinary research and innovative solutions to enhance crop productivity and sustainability in the face of global environmental challenges.

Effect of Phosphorus Levels on Morphology

Phosphorus, an essential nutrient for plant growth and development, profoundly influences the morphological characteristics of mungbean plants, thereby shaping their overall architecture and productivity. Phosphorus availability exerts a profound influence on root development and architecture in mungbean plants.

Adequate phosphorus supply stimulates lateral root proliferation and elongation, resulting in a denser and more extensive root system (Bhadoria *et al.,* 2012; Verma *et al.,* 2018; Sadiq *et al.,* 2018; Wang *et al.,* 2016; Wang *et al.,* 2018; Verma *et al.,* 2020; Sun *et al.,* 2020; Yadav *et al.,* 2024; Verma *et al.,* 2024).

For mungbean, the optimal phosphorus (P) concentration in soil typically falls within the range of 20-40 mg/kg of available phosphorus (Kundu & Gupta, 2012). In terms of plant tissue, phosphorus deficiency symptoms generally begin to appear when the P concentration in the plant tissues drops below 0.15-0.20% of dry weight (Liao & Shen, 2016). Symptoms of phosphorus deficiency in mungbean include plants remain green but older leaves have reddish-purplish leaf tips and margins stunted growth and poor root development (Kundu & Gupta, 2012).

This enhanced root exploration facilitates improved nutrient and water uptake from the soil, thereby enhancing the plant's ability to withstand environmental stresses and nutrient deficiencies (Fig. 1).

Effect of Phosphorus Levels on Yield

Phosphorus application has a profound impact on the yield of mungbean, influencing key growth parameters such as root development, nodulation, pod formation, and seed weight. Studies indicate that phosphorus deficiency can significantly reduce grain yield due to poor root proliferation and inefficient nutrient uptake (Ali *et al*., 2018). Research by Singh *et al*., (2020) demonstrated that an optimal application of 45 kg P_2O_5 per

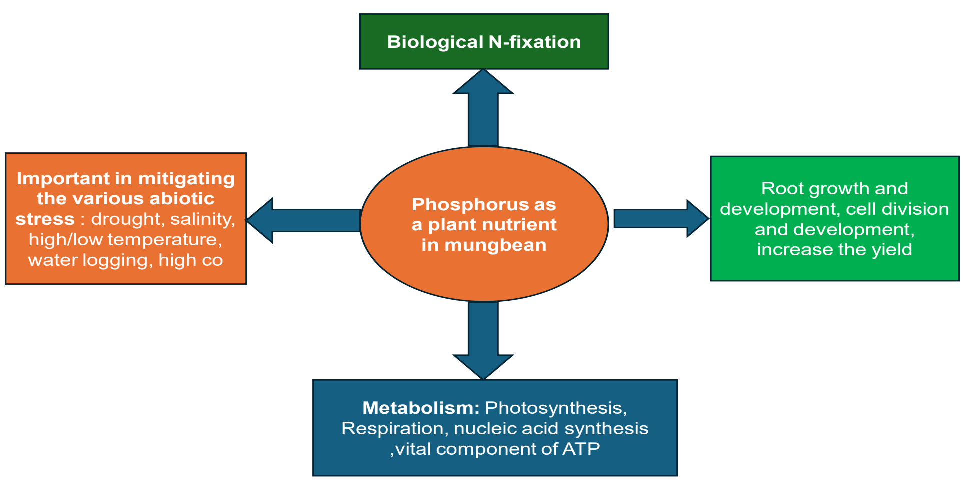


Fig. 1: Effect of Phosphorus on morphological and metabolic changes in mungbean

hectare resulted in a notable increase in mungbean yield, improving both pod number and seed weight. Additionally, the use of phosphorus-solubilizing bacteria (PSB) has been found to enhance phosphorus availability and uptake, thereby further improving mungbean productivity (Sharma *et al.*, 2019). These findings underscore the importance of balanced phosphorus fertilization in maximizing mungbean yield while ensuring sustainable soil nutrient management.

Shoot Growth and Architecture

Optimal phosphorus levels contribute to robust shoot growth and architectural development in mungbean plants. Studies have demonstrated that phosphorus supplementation enhances shoot biomass accumulation, resulting in taller plants with increased leaf area and greater canopy coverage (Shukla *et al.,* 2017; Verma *et al.,* 2018a; Sadiq *et al.,* 2018; Kumari *et al.,* 2020; Li *et al.,* 2017; Chen *et al.,* 2019; Zhou *et al.,* 2021, Tomar *et al.*, 2024; Tiwari and Singh, 2024).

Reproductive Structures

Phosphorus availability also influences the development and morphology of reproductive structures in mungbean plants. Adequate phosphorus supply has been associated with increased flower production, enhanced pollen viability, and improved pod set and filling (Kumar *et al.,* 2019; Sadiq *et al.,* 2018; Chen *et al.,* 2017; Gao *et al.,* 2018; Sun *et al.,* 2020; Singh *et al.,* 2024; Singh and Arora, 2023). Moreover, phosphorus plays a crucial role in promoting flower initiation and development, ensuring optimal reproductive success and seed set.

Effect of Phosphorus Levels on Biochemical Properties

Phosphorus, a vital nutrient for plant metabolism, profoundly influences the biochemical properties of mungbean plants, orchestrating a cascade of molecular processes crucial for growth, development, and stress tolerance.

Enzymatic Activity

Phosphorus availability exerts a significant influence on enzymatic activities involved in various metabolic pathways in mungbean plants. Adequate phosphorus supply stimulates the activity of phosphatases, enzymes responsible for catalyzing the hydrolysis of organic phosphorus compounds, thereby releasing inorganic phosphorus for plant uptake (Vance *et al.*, 2003; Kumari *et al.*, 2020; Li *et al.*, 2017; Zhou *et al.*, 2021; Sun *et al.*, 2020; Rathora *et al.*, 2024; Patel and Sharma, 2024). Additionally, phosphorus plays a pivotal role in activating ATPases, enzymes involved in ATP hydrolysis, which serve as the primary energy source for numerous biochemical reactions in plants (Cakmak *et al.*, 2010; Chen *et al.*, 2017; Gao *et al.*, 2018; Wang *et al.*, 2018; Ashraf and Harris, 2013).

Nutrient Uptake and Assimilation

Phosphorus availability influences the uptake, translocation, and assimilation of essential nutrients in mungbean plants. Adequate phosphorus supply enhances the efficiency of nutrient uptake systems, including ion transporters and channels, facilitating the acquisition of macro- and micronutrients from the soil solution (*Babu et al.*, 2017; Verma *et al.*, 2018; Jain & Meena (2024a); Sadiq *et al.*, 2018; Verma *et al.*, 2020; Kumari *et al.*, 2020; Li *et al.,* 2017; Zhou *et al.,* 2021; Sun *et al.*, 2020; Patel and Sharma, 2024a; Pandey *et al.*, 2024,). Moreover, phosphorus acts as a key regulator of nutrient partitioning within the plant, directing resources toward essential metabolic processes such as photosynthesis, respiration, and protein synthesis.

Osmotic Regulation and Stress Tolerance

Phosphorus plays a crucial role in osmotic regulation and stress tolerance mechanisms in mungbean plants. Under conditions of moisture stress, phosphorus accumulation in the cytoplasm contributes to osmotic adjustment, maintaining cell turgor pressure and hydration status (Ashraf and Harris, 2013; Chen *et al.,* 2017; Gao *et al.*, 2018; Wang *et al.,* 2018; Sun *et al.,* 2020,

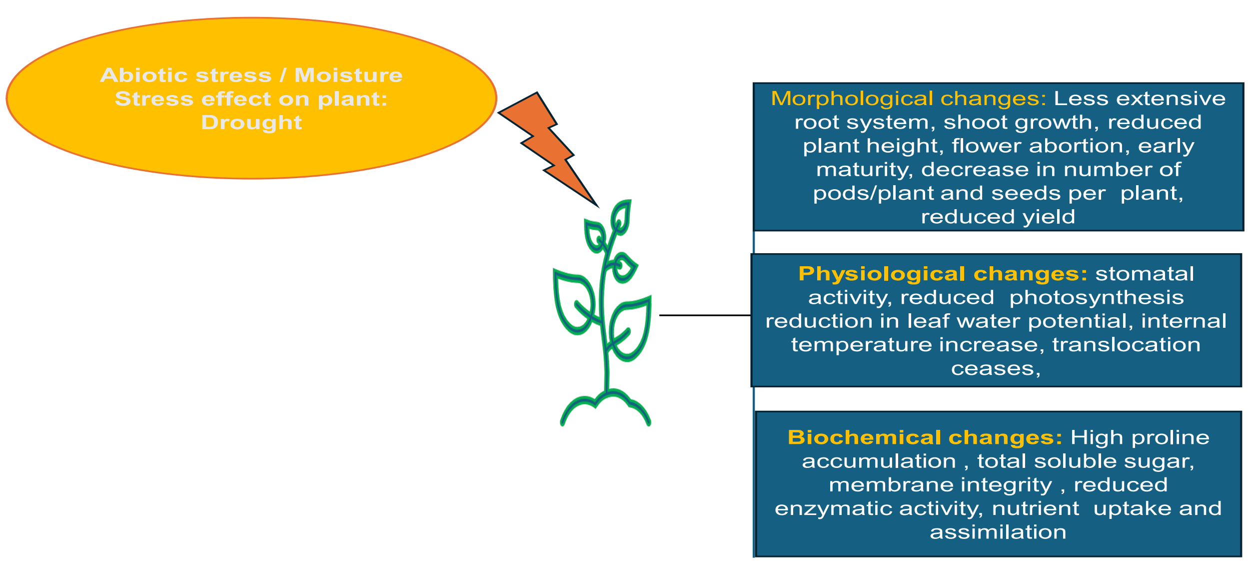


Fig. 2: Effect of moisture stress on morphological changes, Physiological changes, and Biochemical changes in mungbean

Naeem *et al.,*2024; Mishra *et al.,* 2024). Furthermore, phosphorus-enriched plants exhibit enhanced synthesis and accumulation of compatible solutes such as sugars, amino acids, and polyols, which act as Osmoprotectants, stabilizing cellular structures and preserving membrane integrity under stress conditions.

Impact of Moisture Stress on Morphological Responses

Moisture stress poses a significant challenge to mungbean cultivation, profoundly affecting its morphological characteristics and growth patterns (Fig. 2).

Root Morphology

Moisture stress triggers profound alterations in mungbean root morphology as the plant strives to adapt to limited water availability. Under conditions of drought, mungbean plants exhibit reduced root elongation and lateral root proliferation, resulting in a shallower and less extensive root system (Ashraf and Harris, 2013; Farooq *et al.,* 2009; Kumari *et al.,* 2020; Li *et al.,* 2017; Zhou *et al.,* 2021; Naeem *et al.,*2024; Mishra *et al.,* 2024;). Additionally, root hairs, critical for nutrient and water uptake, become sparse, further compromising the plant's ability to access soil resources.

Shoot Growth and Architecture

Moisture stress exerts a pronounced inhibitory effect on shoot growth and architectural development in mungbean plants. As water becomes scarce, mungbean plants undergo stunted growth, with reduced internode elongation and leaf expansion (Farooq *et al.,* 2009; Kumari *et al.,* 2020; Verma *et al.,* 2017; Babu *et al.,* 2017; Li *et al.,* 2017; Chen *et al.,* 2019; Sun *et al.,* 2020, Kumar *et al.,* 2024; Khan *et al.,*2024;).Consequently, plant height is compromised, and leaf area is diminished, leading to decreased light interception and photosynthetic activity.

Reproductive Structures

Moisture stress profoundly impacts the development and morphology of reproductive structures in mungbean plants, thereby affecting yield potential. Drought-induced water deficits often result in flower abortion, reduced pollen viability, and impaired pod set and filling (Kumari *et al.,* 2020; Chen *et al.,* 2017; Gao *et al.,* 2018; Wang *et al.,* 2018; Sun *et al.,* 2020; Kumar *et al.,* 2024; Khan *et al.,*2024). Consequently, there is a decrease in the number of pods per plant and seeds per pod, leading to yield losses and compromised seed quality.

Impact of Moisture Stress on Yield

Moisture stress is one of the most significant abiotic factors that can severely reduce the yield of mungbean, a crop that is sensitive to water availability during its critical growth stages. Mungbean is particularly vulnerable to water stress during flowering, pod formation, and seed filling stages, leading to substantial yield losses. During periods of drought or insufficient irrigation, mungbean plants exhibit various physiological responses, such as reduced photosynthetic activity, leaf wilting, and a decrease in the number of pods and seeds per plant. Studies have shown that water stress significantly impacts key agronomic traits, including seed size, biomass production, and overall plant growth (Bhimire *et al.*, 2021; Singh *et al.*, 2019). Research indicates that moisture stress during the flowering to pod-filling period is particularly detrimental to mungbean productivity. At this time, the plant requires sufficient water to support the formation of pods and seeds. Water deficits during these stages result in a reduced number of pods and smaller seed size, leading to a decrease in overall grain yield (Zhang *et al.*, 2017). Additionally, severe moisture stress can induce premature leaf senescence, reduce nitrogen fixation by root nodules, and decrease the efficiency of nutrient uptake (Verma *et al.*, 2020).

Impact of Moisture Stress on Biochemical Properties

Moisture stress imposes significant alterations in the biochemical milieu of mungbean plants, triggering adaptive responses aimed at maintaining cellular homeostasis and mitigating oxidative damage.

Enzymatic Activity

Moisture stress profoundly influences enzymatic activities crucial for metabolic processes and stress tolerance in mungbean plants. Under drought conditions, there is a modulation of enzyme activities involved in antioxidant defense mechanisms, such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) (Kumari *et al.*, 2020; Farooq *et al.,* 2009; Babu *et*

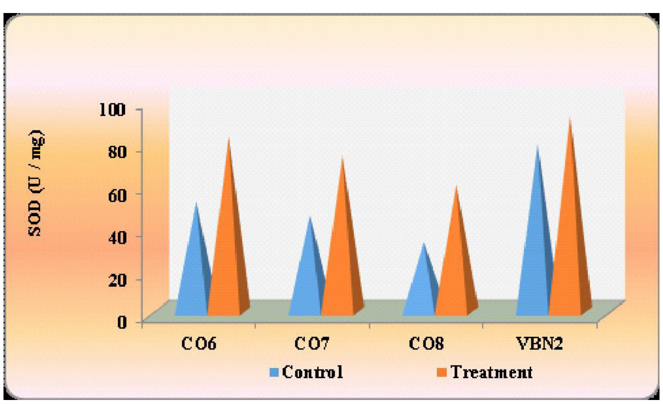


Fig. 3: Effect of drought stress on superoxide dismutase (SOD) activity in mungbean

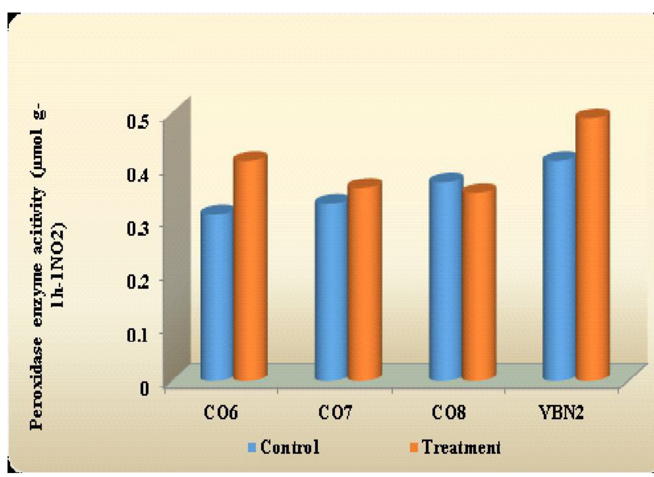


Fig. 4: Effect of drought stress on peroxidase enzyme in mungbean

al., 2017; Li *et al.,* 2017; Chen *et al.,* 2019; Sun *et al.,* 2020; Rathora*et al.,* 2024; Patel and Sharma, 2024; Sajitha *et al.,*2022) (Fig. 3 & 4). These enzymes play a pivotal role in scavenging reactive oxygen species (ROS) generated during periods of oxidative stress, thereby protecting cellular components from oxidative damage.

- *Proline*

Moisture stress induces changes in various biochemical constituents of mungbean, including proline content. Proline, an amino acid, plays a crucial role as an Osmoprotectant and antioxidant, aiding in stress adaptation and tolerance. Under conditions of moisture stress, mungbean plants often exhibit elevated proline levels as part of their stress response mechanism.

Sajitha *et al*., (2022) concluded that the overall average increase in proline is two-fold under stress after having imposed drought stress for 10 days, the proline content of leaf tissues varied from 21.81 to 47.45μg g-1 fr.wt. All the varieties showed an increased level of proline under stress. Proline accumulation varied from 21.81 μg g^{-1} fr.wt (CO7) to 47.45 μg g^{-1} fr.wt in control plants while stressed plants varied from 46.40 μg g^{-1} fr.wt (CO8) to 83.70 μg g^{-1} fr.wt (Fig. 5). Kumari *et al*., (2020) demonstrated a significant increase in proline content in mungbean plants subjected to moisture stress. The study found that under drought conditions, mungbean plants accumulated higher levels of proline in their tissues compared to well-watered controls. This elevation in proline content serves as a physiological adaptation to osmotic stress, helping to maintain cell turgor pressure and cellular hydration, thereby enhancing the plant's ability to withstand water deficits. Additionally, studies by Li et al., (2023) and Wang et al., (2024) corroborated these findings, reporting similar increases in proline content in mungbean under moisture-stress conditions. Li et al., (2023) conducted a comprehensive analysis of proline accumulation in mungbean genotypes exposed to varying levels of water availability, highlighting genotype-specific responses to moisture stress. Similarly, Wang et al., (2024) investigated the temporal dynamics of proline accumulation in mungbean plants subjected to progressive drought, revealing a gradual increase in proline levels as the duration of water deficit intensified.

Metabolic Pathways

Moisture stress triggers dynamic alterations in metabolic pathways essential for plant growth, development, and stress adaptation. Under conditions of drought, there is a shift in carbon partitioning towards osmolyte synthesis and stress-responsive metabolites, such as proline, soluble sugars, and polyols (Farooq *et al.,* 2009; Kumari *et al.,* 2020; Wang *et al.,* 2016; Sun *et al*., 2020; Jain and Meena, 2024). These Osmoprotectants act as compatible solutes, stabilizing cellular structures and maintaining cellular hydration under water-deficit conditions.

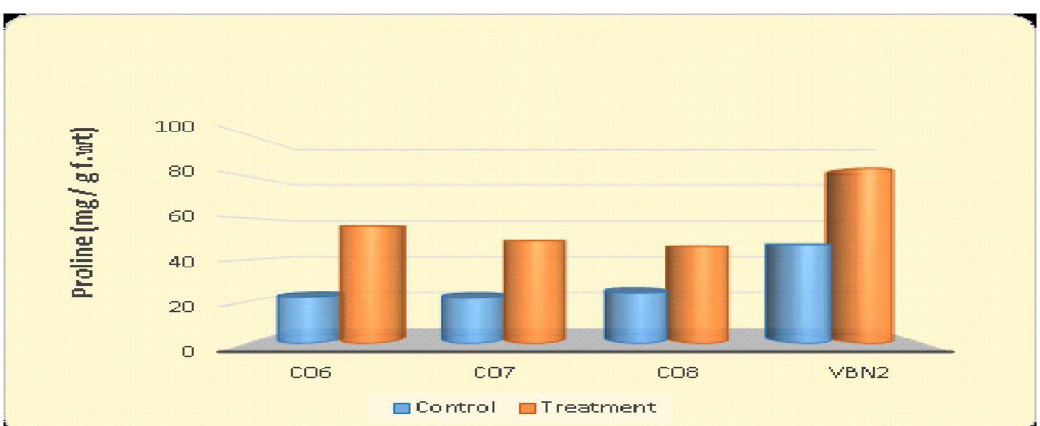
Membrane Integrity

Moisture stress compromises membrane integrity and fluidity in mungbean plants, leading to cellular dehydration and ion leakage. Under drought conditions, there is an increase in lipid peroxidation, resulting in the accumulation of malondialdehyde (MDA) and other lipid peroxidation products (Farooq *et al.,* 2009; Li *et al.,*2017; Chen *et al.,* 2019). This oxidative damage to membrane lipids disrupts cellular functions and exacerbates physiological stress. Moreover, moisture stress-induced alterations in membrane properties can affect the activity of membrane-bound enzymes and transport proteins, further impacting nutrient uptake and metabolic processes.

Interaction Effect of Phosphorus Level and Moisture Stress

Interaction Effect of Phosphorus Level and Moisture Stress on Morphological Properties

The interaction between phosphorus levels and moisture stress significantly influences the morphological characteristics of mungbean plants, dictating their adaptive responses to varying environmental conditions. Under optimal moisture levels and adequate phosphorus supply, mungbean plants typically exhibit vigorous growth, with well-developed root systems characterized by extensive lateral root proliferation and elongation (Bhadoria *et al.,* 2012; Devi & Kumar, 2024; Sadiq *et al.,* 2018; Kumari *et al.,* 2020; Li *et al*., 2017; Sun *et al.,*



Source: Sajitha *et al.,* (2022)
Fig. 5: Proline accumulation(μg/g fr.wt^{-1}) in mungbeans

2020; Use). This robust root architecture enhances nutrient and water uptake efficiency, promoting lush shoot growth and canopy development. However, in the presence of moisture stress coupled with phosphorus deficiency, mungbean plants often display reduced root elongation and shoot biomass accumulation, resulting in shallower root systems and stunted canopy growth (Kumar *et al*., 2019; Gao *et al.,* 2018; Wang *et al.,* 2018; Chen *et al.,* 2019; Zhou *et al.,* 2021; Rathora *et al.,*2024; Patel and Sharma, 2024;). Conversely, phosphorus-enriched plants exhibit greater resilience to moisture stress, maintaining root elongation and shoot development even under water-limited conditions.

Interaction Effect of Phosphorus Levels and Moisture Stress on Yield

The interaction of phosphorus and moisture stress directly impacts several agronomic traits that are critical for mungbean yield. First, phosphorus influences seed formation by supporting the development of pods and seeds. During the flowering and pod-filling stages, which are particularly vulnerable to moisture stress, adequate phosphorus can mitigate reductions in pod number and seed size. Studies have shown that phosphorus-enriched mungbean plants have better pod set and larger seeds, even under drought conditions, thereby improving overall yield (Vance *et al*., 2003). Second, phosphorus enhances photosynthesis and nutrient mobilization, both of which are critical for plant growth during moisture stress. Phosphorus application has been shown to sustain photosynthetic activity under drought by ensuring sufficient energy production through ATP. Furthermore, phosphorus facilitates the mobilization of other nutrients like nitrogen, which are essential for plant metabolism and growth. This is particularly important under moisture stress, where nutrient uptake is often reduced due to limited water availability (Gupta *et al*., 2024; Kumari *et al*., 2020).

Interaction Effect of Phosphorus Levels and Moisture Stress on Biochemical Properties

The interaction between phosphorus levels and moisture stress intricately influences the biochemical properties of mungbean plants, orchestrating a complex interplay of metabolic pathways and stress response mechanisms. Mung bean is sensitive to water stress which significantly affects the root system, shoot biomass production and final yield. Under optimal moisture conditions and adequate phosphorus supply, mungbean plants typically exhibit enhanced enzymatic activities associated with nutrient mobilization and assimilation, such as phosphatases and ATPases, facilitating efficient nutrient uptake and utilization (Vance *et al.,* 2003; Kumari *et al.,* 2020; Li *et al.,* 2017). Additionally, metabolic pathways involved in carbon assimilation, nitrogen metabolism, and osmolyte synthesis are upregulated, ensuring metabolic homeostasis and cellular function. However, in the presence of moisture stress coupled with phosphorus deficiency, mungbean plants may experience reduced enzymatic activities and metabolic fluxes, compromising nutrient acquisition and stress tolerance mechanisms (Gupta et al., 2024). Conversely, phosphorus-enriched plants demonstrate enhanced resilience to moisture stress, maintaining enzymatic activities and metabolic pathways critical for stress adaptation and survival.

Conclusion

The intricate interplay between phosphorus levels and moisture stress exerts profound effects on the morphological and biochemical responses of mungbean plants, influencing their growth, development, and productivity. Optimal phosphorus availability enhances root proliferation, shoot growth, and reproductive success, thereby promoting greater resilience to environmental stresses and maximizing yield potential. Conversely, moisture stress imposes constraints on mungbean morphology and biochemistry, leading to compromised root and shoot development, reduced reproductive output, and impaired metabolic functions. However, the interactive effects of phosphorus and moisture stress underscore the importance of holistic nutrient management strategies in mitigating the adverse impacts of environmental fluctuations on mungbean cultivation. By integrating insights from diverse research endeavors, this review elucidates the multifaceted dynamics governing mungbean physiology under varying environmental conditions, providing a foundation for the development of resilient and sustainable agricultural practices. Moving forward, continued interdisciplinary research efforts are warranted to unravel the complexities of nutrient-stress interactions and devise innovative solutions to enhance mungbean productivity in the face of environmental challenges.

Acknowledgment

We express our sincere gratitude to Integral University, Lucknow, India, for providing the necessary resources and support for this study and provided MCN Number- MCN0002843 for this review paper, special thanks to the Department of Agriculture, IIAST for their guidance. We also acknowledge the contributions of our fellow researchers, whose collaboration enhanced the quality of this study. Additionally, we extend our appreciation to all individuals who directly or indirectly contributed to the successful completion of this project.

Conflict of interest

The authors have declared no conflict of interest.

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