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Review Article

Impacts of Water Logging on Soil Microbial Intentions and Mung Bean (*Vigna radiata* L.) Physiology

Abdul Hannan Afzal[1*], Hassan Zubair[2], Shahzad Abid[3], Muhammad Shahzaib[4], Muhammad Hassan[2], Sarmad Khalid[2], Muhammad Shoaib[2], Aziz Ahmad[2], Muhammad Zaib[5]

[1]Department of Plant Breeding and Genetics, [2]Department of Agronomy, University of Sargodha, Sargodha 40100, Pakistan

[3]Department of Agronomy, Bahauddin Zakariya University, Multan 60000, Pakistan

[4]Department of Plant Breeding and Genetics, PMAS Arid Agriculture University, Pakistan

[5]Department of Soil and Environmental Sciences, University of Sargodha, Sargodha 40100, Pakistan

*Corresponding Author E-mail: hannanafzal223@gmail.com

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ABSTRACT

The mung bean (Vigna radiata L.) is an important pulse crop known for its high protein content and adaptability to tropical and subtropical regions, particularly in Asia. Despite of their importance as a source of protein, most noticeably that, waterlogging negatively affects their growth and yield. Waterlogging, resulting from factors like compacted soil and excessive irrigation, leads to hypoxic conditions and negatively affects various physiological and morphological aspects of mung bean plants. The impact of waterlogging on mung beans at different growth stages emphasises its detrimental effects on root growth, leaf area, chlorophyll content, photosynthesis, and biomass. Waterlogging disrupts nutrient uptake, causing deficiencies and hindering overall plant adaptation. The molecular responses and metabolic changes in mung beans under waterlogging stress can upset the shift to anaerobic metabolism and the synthesis of specific proteins. Microbial interactions in the rhizosphere soil and their influence on mung bean growth during waterlogging also play an important role in mung bean growth and yield. Tolerance mechanisms, including morphological adaptations and physiological changes, are explored, offering insights into selecting tolerant genotypes. Agronomic strategies, such as the use of cytokinin and gibberellin acid used for mitigating waterlogging effects and enhancing mung bean resilience.

Keywords: *Waterlogging, molecular response, physiological adaptations, morphological Changes, nutritional uptake*

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INTRODUCTION

The mung bean (*Vigna radiate* L.) is a significant pulse crop with high content of digestible protein (about 25-28%) is due to N_2 fixing mechanism (Kumar et al., 2013). Due to its greater adaptability, it is widely grown in tropical and subtropical Asia. Considered to be an indigenous crop of India, mung bean has been grown there since prehistoric times (Kassam et al., 2010). Mung beans are regarded as a high-quality protein source (Engel, 1978). Its various food products, which have developed and gained popularity throughout the subcontinent, include dhals (thick stews made from split and dehulled grains), sweets, snacks, and savoury food items (Adsule et al., 1986), in contrast, eastern nations like China where are foods like cakes, sprouts, noodles, and soups evolved, the Philippines as well as in Iran and Thailand. The predominant agricultural activity in the Punjab Province revolves around cultivating major traditional crops like grain, rice, and maize. Nevertheless, certain farmers in the Punjab region of Pakistan have transitioned to alternative crops, including ornamental plants (Chen et al., 1988 Ali et al., 2023). Soil properties are pivotal for eco-friendly farming practices. They profoundly influence agricultural sustainability. Understanding and managing these properties is essential for environmentally conscious cultivation (Zaheer et al., 2023; Zaib et al., 2023g).

Mung bean plants are upright, and branches near the plant's top bear pods in clusters. 8–15 seed grains are found in pods (Murakami et al., 1990). The grains have a brown or green shading and are globose in form with a hilum that is flat (Dahiya et al., 2015). With a short lifespan of 70–90 days and minimal input requirements, mung bean is a significant warm-season annual grain legume. Indeed, mung beans offer vegetarians an enhanced and more affordable source of easily digestible proteins. Thus, another way to refer to mung bean is as "the poor man's meat" (Sehrawat et al., 2020). The arrangement and bonding of soil particles significantly impact soil physical characteristics, affecting water movement, aeration, root penetration, and nutrient accessibility. Inadequate soil structure may result in compaction, reduced water infiltration, and hindered root growth. Utilizing nanoparticles, with their distinctive physicochemical traits and expansive surface area, holds promise for enhancing soil structure and aggregation through diverse mechanisms. Nanoparticles can alter the behavior of soil colloids, particularly clay particles, mitigating issues like dispersion commonly found in waterlogged and compacted soils (Zaib et al., 2023g; 2023h; 2023d).

Mung beans are an essential grain legume in rain-fed farming systems in arid and intermediate zones because they can be grown in low-moisture and low-fertility environments (Ranawake et al., 2011). Free standing water will always be on the soil surface when the surface layer's soil water content is at least 20% higher than the field's carrying capacity (Irfan et al., 2010). Compacted soil, excessive irrigation, rainfall following irrigation, and inadequate surface and internal soil drainage—such as in heavy clay, clay pan, or duplex soil—are the main causes of it (Thongthip et al., 2023). In a short amount of time, elevated water content in the soil causes hypoxic conditions or a drop in oxygen levels. Plant roots thus experience anoxia, or total lack of oxygen (Ashraf, 2012). This condition severely limits the growth and productivity of crops.

Waterlogging stress can arise from various direct (inadequate irrigation techniques) and indirect (global warming) human-caused and spontaneous (meteorological) factors, which can change the metabolic processes of plants, architecture, and eco-geographical dispersion based on plant responses. The issue is expected to continue to grow in the near future due to the Earth's average temperature changing quickly (Irfan et al., 2010). There have been reports of significant reductions in yield in numerous legumes, such as soybean and mung bean, after just one day of waterlogging (Amin et al., 2017). Waterlogging is something that mung beans cannot tolerate, especially in their early growth stages. When the plants are young, significant losses in grain yield have also been noted (Kumar et al., 2013). Waterlogging is said to cause a decrease in growth and chlorophyll content, as well as to kill roots and decrease mung bean yield (Amin et al., 2017). Flooding or waterlogging limits nodule activity and nitrogen fixation while lowering oxygen concentrations around the roots of the submerged plants. Therefore, the wet tropics, where annual precipitation exceeds 1,000 mm, are unsuitable for mung bean cultivation (Kumar et al., 2013).

Crop Physiology and waterlogging

There are nine different physiological growth phases that the mung bean plant goes through. Sowing to germination, germination to emergence, the basic vegetative phase (also known as the juvenile phase), a photoperiod-induced phase ending at floral initiation, the flower development phase ending at 50% flowering, the lag phase before the start of grain filling, the linear phase of grain filling, the interval between the end of grain filling and physiological maturity, and the harvest-ripe phase before grain harvest are the physiological phases (Chauhan et al., 2010). Depending on the growth stage, length of time, and type of soil, waterlogging has been demonstrated to impact mung bean genotypes in a number of morpho-physiological ways (Sharma & Dhanda, 2014). Physiological disruptions from waterlogging caused mung bean genotypes to grow less and produce less dry matter, photosynthesis, and pods. These effects were observed in other beans as well. Among sensitive genotypes, the effect on plant growth was more noticeable, especially in terms of leaf area and growth rate. Plants that have been waterlogged will have yellowing because of the detrimental effects on the stability of the cell membrane, the relative water content, and the chlorophyll content.

Kumar et al. (2013) stated that numerous studies have documented a decrease in stomatal conductance in mung bean plants under waterlogged conditions, which is accompanied by a decrease in CO_2 assimilation and a reduction in growth (Wagner & Dreyer, 1997). Waterlogging in mung bean has a detrimental effect on a number of growth parameters that precede the effect on yield, such as root growth, leaf area, leaf chlorophyll content, photosynthesis, stomatal conductance, water use efficiency, and total biomass (Ahmed et al., 2002)

Impacts of waterlogging

Microbial intentions of soil

The "rhizosphere soil" is the area where microbial interactions are more common and is defined as the soil within 2 mm of the root system (Ju et al., 2020). Plant roots secrete a substance that is a major source of food for microorganisms and energy for the population of microbes (Williams & de Vries, 2020). The soil ecosystem is greatly impacted by microbial communities connected to the root system, which also have an impact on plant growth and health and numerous soil biochemical processes (Ali et al., 2022c; Riaz et al., 2022c; Sun et al., 2022; Zaib et al., 2023a; 2023c). Plant rhizosphere soils are home to a variety of microbial communities that can impact the normal activities and metabolism of the plants by influencing soil fertility and nutrient cycling.

Soil fertility can be compromised by various processes leading to soil pollution when they infiltrate the soil solution. (Ali et al.,2022d; Fernández-Gómez et al., 2019; Road et al., 2023). However, changes in the environment, particularly in the soil's moisture, can affect soil microorganisms (Zhou et al., 2023). The microbial activity in the mung bean rhizosphere is altered by the wet soil microbiological environment. Soil nutrients are closely associated with changes in soil microbial diversity during water logging or wastewater use (Ali et al., 2022b; Auffret et al., 2016). Rhizosphere and non-rhizosphere soil environments are complicated by the combined effects of abiotic stress(waterlogging) and the root system (Gong et al., 2020).

Nutrients uptake and utilization

Nutrients are the critical requirement of any and required by the crop in suitable concentration for their normal physiological and biochemical functions (Ali et al., 2022a, 2023). Because of the changes in the way plants absorb nutrients, mineral nutrition in waterlogged ground may restrict plant growth (Steffens et al., 2005; Irfan et al., 2023). Waterlogged soil poses challenges to plant growth, leading to nutrient deficiencies and poor adaptation. Waterlogging affects root activity and initiates leaf yellowing in mung beans (Rao et al., 2002). Adventitious roots quickly develop post-flooding, providing essential oxygen (Gliński & Stępniewski, 2018). Water logging and soil problems cause a reduction in the uptake of N, P, K, and Ca (Riaz et al., 2022a, 2022b). Plants with standing water exhibit chlorosis and older leaves with necrotic spots. Low redox potential in wet soils can cause Mn toxicity and N deficiency by producing plant-available Mn^{2+} and encouraging denitrification of NO_3^- (Steffens et al., 2005). Root metabolism and growth are suppressed in these anaerobic conditions because the plant's energy status is impacted by the absence of oxygen (Drew, 1988). Water logging lowers root oxidazibility, leaf catalase activity, and leaf superoxide dismutase activity. Excess moisture depresses mung bean characteristics and yield (Hamid et al., 1991). Nutrient supply's impact on waterlogging tolerance is emphasized. Nitrogen and potassium application alleviates waterlogging effects, enhancing growth and nutrient uptake and the combined use of fertilizers proves beneficial (Ashraf et al., 2011; Zaib et al., 2023f)

Morphological Changes

Waterlogging has an impact on morphological trait changes. Plant growth, development, and survival are significantly impacted by the lack of oxygen, either totally absent or severely reduced, in crops grown in wet conditions. Waterlogging is a major abiotic stressor for mung bean production that has a negative impact on pod and seed yield (Amin et al., 2016). More than half of the total yield of mung beans was lost due to waterlogging the crop for more than a week. Plant varieties that survive under waterlogging can adapt by delaying of flowering (Celedonio et al., 2016). Waterlogging can cause plant death of legume crops during or after waterlogging, as well as decrease photosynthesis, plant growth, grain yield, nodule function and survival, and biological N fixation. Enzyme activities involved in photosynthesis were suppressed during waterlogging. Plant death resulted from a decrease in the leaves' capacity to synthesize chlorophyll, which caused senescence, yellowing, and peeling of the leaves and a blockage in the growth of new leaves (Wu & Yang, 2016).

Metabolic Changes and molecular response

Plants must contend with hypoxia, or the lack of oxygen, and anoxia, or the total absence of oxygen, as environmental challenges throughout their lives. Natural events that cause root hypoxia or anoxia include seed imbibitions, flood irrigation, floods, and excessive rainfall (Sairam et al., 2011**).** The principal effects of oxygen deprivation include a decrease in adenylate energy charge (ATP/ATP + ADP + AMP), cytoplasmic acidification, anaerobic fermentation, elevation of cytosolic Ca2+ concentration, changes in the redox state [NAD(P)H/NAD(P)], and a reduction in membrane barrier function (Ricard et al., 1994). Water-logging-induced increase in the activity of diphenylene iodonium chloride-sensitive NADPH oxidase-dependent superoxide production, as well as an increase in the expression of NADPH oxid*ase*, has been reported (Sairam et al., 2011).

In response to oxygen deprivation, plants transition from oxidative to exclusively substrate-level phosphorylation of ADP to ATP; the latter reactions primarily entail fermentation and glycolysis. During fermentation, only two molecules of ATP are produced for every glucose molecule, compared to 38 molecules during oxidative phosphorylation. Two-dimensional electrophoresis analysis of the anaerobic response in root cells revealed a set of roughly twenty anaerobic proteins that were synthesized during low oxygen conditions, while the synthesis of the normal aerobic proteins was severely suppressed (Sachs et al.,1980). The only source of energy is the glycolytic-fermentation pathway, which produces only 2 ATP per mole of glucose as opposed to 38 via the glycolysis-Krebs Cycle-Electron transfer chain. Based on this, it would appear that a species or genotype with a higher concentration of carbohydrates in its roots and an effective metabolic mechanism linked to the mobilization of carbohydrates and the fermentation pathway will be better able to withstand oxygen loss (Sairam et al., 2009).

Aspect	Impact on Plants
Morphological Traits	- Waterlogging affects plant growth, development, and survival.
	- Lack of oxygen in wet conditions impacts crops, leading to reduced oxygen supply.
	- Major abiotic stressor for mung bean production, causing a significant decline in pod and seed yield.
	- Prolonged waterlogging can result in a loss of more than half of the total mung bean yield.
	- Some plant varieties adapt by delaying flowering under waterlogged conditions.
Physiological Responses	- Waterlogging causes plant death, decreases photosynthesis, and inhibits plant growth, grain yield, and nodule function.
	- Enzyme activities involved in photosynthesis are suppressed during waterlogging.
	- Decrease in leaves' ability to synthesize chlorophyll leads to senescence, yellowing, and growth inhibition.
Metabolic and Molecular Responses	- Oxygen deprivation induces metabolic changes, shifting from oxidative to substrate-level phosphorylation.
	- Adenylate energy charge decreases during oxygen deprivation.
	- Cytoplasmic acidification, anaerobic fermentation, and changes in cytosolic Ca2+ concentration occur.
	- Increase in diphenylene iodonium chloride-sensitive NADPH oxidase and superoxide production during waterlogging.
	- Plants transition to the glycolytic-fermentation pathway for energy production under oxygen-deprived conditions.
	- Species or genotypes with higher carbohydrate concentration and effective metabolic mechanisms better withstand oxygen loss.

Crop yield

Too wet conditions prevent roots from growing, restricting the amount of soil that can be explored for water and nutrients. The metabolic processes of roots are disturbed by low oxygen levels, which affects nutrient uptake and general plant health (Colmer, 2003). Reduced oxygen levels impact chloroplast performance, which lowers photosynthetic activity. As a result, less glucose is produced, which reduces the amount of energy available for development and reproduction (Setter et al., 2009). Waterlogging interferes with the absorption of nutrients, leading to deficiencies in important elements like potassium, phosphorus, and nitrogen. The growth and yield of plants are further hampered by this imbalance. Prolonged waterlogging creates favorable conditions for soil-borne pathogens, increasing the risk of root diseases. This exacerbates the overall stress on the mung bean plants (Amin et al., 2015).

Tolerance of the various crops to waterlogging

Tolerating waterlogging in various crops, including mung bean, has been determined by selecting for a number of characteristics, plant height, dry weight, photosynthetic rates, stomatal conductance, PSII photochemical efficiency, PSII quantum efficiency of dark-adapted leaves, excitation pressure, and chlorophyll content of the leaves are a few of these (Ahmed et al., 2002). Plants have developed a variety of tolerance mechanisms to withstand waterlogging, which is a highly complex phenomenon. These mechanisms include changes in physiological and morphological parameters like adventitious root production, parenchyma development, and alteration in leaf (epinasty) and shoot morphology, while also maintaining higher levels of gas exchange and parameters related to chlorophyll and fluorescence (Smethurst & Shabala, 2003).

Under waterlogging, tolerable genotypes showed increased adventitious root proliferation, highlighting its importance for quick recovery of root growth. Comparable characteristics, like decreased root decay and adventitious root formation with aerenchyma, have been documented in pulses underscoring their significance in bestowing resistance to waterlogging. All mung bean genotypes showed a decrease in nodules per plant during waterlogging, but tolerant genotypes kept more nodules per plant. Kumar et al. (2013) studied that the quantity and colour of the leaves could be a key factor in protracted waterlogging. The correlation results showed that the quantity of leaves influences seed yield and is necessary for mung bean recovery from waterlogging conditions. When there is waterlogging, the mung bean plants that keep their leaves can take up oxygen from them and lessen the effect of the roots' decreased ability to absorb oxygen. Additionally essential to sustaining the photosynthetic rate in waterlogged conditions is the leaf's greenness (Ren et al., 2016). When choosing mung bean lines that could withstand waterlogging, the quantity and greenness of the leaves served as crucial markers. Additionally, the quantity of leaves was a crucial characteristic for the potential for seed yield under waterlogging circumstances (Thongthip et al., 2023).

While the better maintenance of carotenoid levels was shown by tolerable genotypes, suggesting a protective role for waterlogging tolerance. Under conditions of waterlogging stress, mung bean genotypes showed modifications in leaf respiration and a decrease in photosynthesis. Faster recovery after waterlogging was observed in genotypes that were tolerant, indicating less damage to the photosynthetic apparatus. With tolerant genotypes retaining more dry matter, waterlogging decreased the total dry weight. The main causes of the decrease in seed yield were pod setting and fewer pods per plant (Kumar et al., 2013) Treating waterlogged-stressed mung bean plants with cytokinin (CK) or gibberellic acid (GA3) improves plant height, stem girth, and biomass. CK and GA3 decrease ROS and MDA levels, enhance antioxidants, proline, and soluble sugars, maintaining water status. Positive effects persist even after a 15-day recovery, improving yield-related features. CK outperforms GA3, suggesting their potential for mitigating waterlogging effects in flash flood-prone areas (Islam et al., 2021; Zaib et al., 2023b)

In regions like Indo-Pak, extreme monsoon rains led to extensive flooding, resulting in substantial economic losses and food shortages (Rehman et al., 2016). Recovery from flooding requires efficient plans to restore productive lands (Zhang et al., 2016). Agronomic strategies involve predictive risk management models and biological knowledge to breed flood-tolerant cultivars (Ali et al., 2021). Excessive water, causing hypoxia in plants, triggers genetic responses, and understanding these molecular elements is crucial for developing climate-resilient varieties to sustain food production for a growing global population (Lee et al., 2011). Continuous research on flooding stress in plants, particularly in mung bean, provides opportunities to identify genomic determinants for climate-resilient crop varieties of mung bean (Zaib et al., 2023e).

CONCLUSION

Waterlogging affects the growth of mung beans by interfering with several physiological and biochemical processes. Reduced oxygen availability from soil flooding prevents roots from taking up nutrients and limits their ability to function. This unfavorable environment causes stunted growth and reduced yield in mung beans.

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