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ABIOTIC STRESS TOLERANCE IN COMMON BEANS; A REVIEW

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ABSTRACT

Phaseolus vulgaris L. (common beans), a legume, is essential for feeding the world's growing population. Common beans are grown in various agroclimatic conditions globally but are prone to abiotic and biotic stresses that limit their productivity. Abiotic stresses include heat and cold stress, moisture stress, and salt stress, with drought stress and salinity stress detrimental to the common bean's growth. By modifying certain traits in response to a specific stress, crop plants, such as common beans, may withstand abiotic stresses. Breeders are constantly attempting to develop abiotic stress-tolerant *Phaseolus vulgaris* L. through innovative approaches. Plant breeders have developed a variety of resistant cultivars of common beans against specific abiotic stresses. This review discusses several abiotic stressors, tolerance mechanisms, and breeding for common bean abiotic stress tolerance.

Keywords: abiotic stresses, common beans, drought stress, tolerance

1. INTRODUCTION

Phaseolus vulgaris L. is the world's most widely consumed edible legume, notably in Latin America and Southern and East Africa. The annual global production of common beans was 34.8 million metric tons in 2020 **[1]**. Common beans are essential in human diets worldwide, particularly in developing nations such as India. The nutritional profile of common beans indicates that they are rich in protein, vitamins, fiber, and minerals and protect against various human ailments, including diabetes, cancer, and heart disease **[2]**. Abiotic and biotic stresses perpetually hamper common bean cultivation and output. Abiotic stress, including drought, water logging, low or high temperature, heavy metals, excessive salinity, and UV radiation, results in disrupted water balance and altered homeostasis and ion distribution at the plant's cellular level. The dependence of plant growth rate and productivity on the differential expression of genes necessitates unraveling and understanding plant response mechanisms under different abiotic stresses after identifying genes involved in such responses. Abiotic stresses negatively impact living organisms in a specified environment, and agriculture is exceptionally vulnerable to abiotic stresses and represents a more significant challenge to the ecosystem and agriculture **[3]**. These stresses limit plants' growth and survival, causing substantial agricultural production decline **[4]**. The two most damaging abiotic stresses, high salinity and drought account for most crop losses worldwide. Farmed common beans are generally not resilient to several abiotic stresses, like drought stress, which damages more than 60% of the dry bean crop worldwide **[5]**.

2. Abiotic Stresses

i. Cold stress

Cold stress, abiotic stress that negatively impacts plant development and agricultural output, includes freezing (0°C) and chilling (0–15°C) **[6, 7]**. Usually, cold stress prevents plants from growing and developing fully and negatively impacts plant cells. The critical process, rigidification of the plant cell membrane that elicits subsequent cold-stress responses in plants, is likewise affected by chilling stress **[8]**. Cold stress decreases protein stability and enzyme actions, such as ROS-scavenging enzymes. Reduced germination, stunted seedlings, leaf chlorosis, reduced leaf expansion, wilting, and in certain instances, tissue death (necrosis) are the visible indications of this stress. The development of plants' reproductive systems is negatively impacted by cold stress. It severely damages the membrane leading to severe dehydration. The acute dehydration in plant cells upon the formation of ice crystals causes freezing damage **[9]**. When subjected to colder temperatures, plants develop a tolerance for freezing. However, in response to low temperatures, the genes for cold response become activated to exhibit resistance. The capacity of crop plants to survive chilling or freezing temperatures varies, and plants native to locations with temperate temperatures are frost-tolerant to varying degrees. Cold acclimation exposes plants to chilling but non-freezing conditions to enhance their freezing resistance. Cold acclimation is related to biochemical and physiological alterations, manifested as variations in small molecule accumulation, cell membrane lipid composition, and gene expression **[10]**.

ii. Moisture stress:

Plant cell water shortage, also known as moisture stress or water deficit, differs from normal levels. When a plant's root zone has a water deficit, and its transpiration rate outpaces its root system's ability to absorb water, moisture stress is said to be present. The leading cause of this water stress situation is a high salt content in the soil, which prevents plant roots from absorbing water from the soil. Moisture stress also impacts a plant's stomatal apertures, typically reducing carbon dioxide absorption due to stomatal closure **[11]**. Closing the stomata often decreases transpiration, minimizing water loss and preventing wilting caused by moisture stress **[12]**. Water stress intensity substantially affects the plant's physiological and biochemical processes. Water stress-induced plant responses are generally quantified by specific physiological parameters like osmotic adjustment, relative water content, water capacity, stomatal regulation, or photosynthesis, which are powerful drought indicators in severe drought **[13]**. The breakdown of proteins and nucleic acids, inhibition of the translocation and synthesis of growth-regulating hormones, sugar and protein hydrolysis leading to an accumulation of soluble sugars and nitrogenous compounds, and slowing of stem growth germination, leaf expansion, cell division, root and fruit development, all result from moisture stress in plants. Crop plants' lifespans are extended by water stress before blooming but are reduced by water stress after flowering **[14]**. *Phaseolus vulgaris* is not grown in various climatic circumstances, including arid locations, since it is thought to be little resilient to moisture stress. Only around 7% of the world's common bean acreage gets enough rainfall, and drought-related production reductions of up to 80% have been seen in a few regions **[15, 16]**.

The incidence of drought is caused by the unequal distribution of precipitation resulting from numerous climatic variations. The extreme drought conditions make soil water inaccessible to plants, causing them to perish prematurely. After plants are subjected to drought, the first symptom is a halt in their growth. During drought, plants limit their metabolic needs and shoot development and then synthesize numerous defensive chemicals by mobilizing metabolites essential for osmotic adjustment. In certain locations, drought may lower grain output by as much as 80 percent, while globally, it impacts about 60 percent of common beans farmed under rainfed circumstances **[1]**. Common beans may experience moisture stress at any growth stage, but some phases, such as the blooming and pod-filling phases, make them more vulnerable to water deprivation **[17, 18]**. Two of the most typical drought patterns in bean production are terminal and intermittent (ID) **[19]**. Drought stress-induced impact on yield and seed quality depends on particular developmental and growth stages and the length and severity of drought **[20]**.

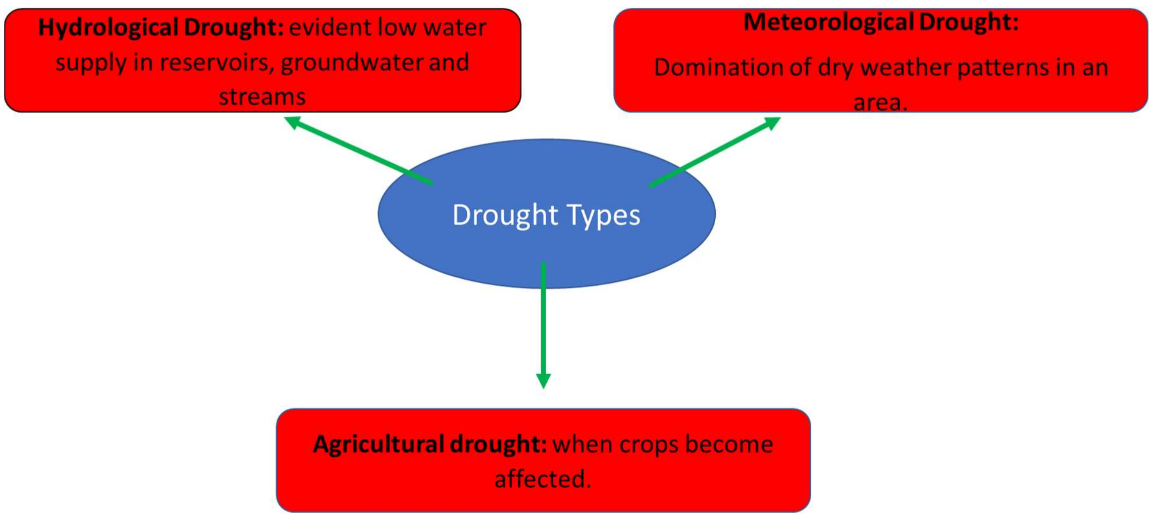

Figure 1: Types of Drought

iii. Salinity stress

Salinity as abiotic stress is one of the greatest worldwide threats to agricultural production, adversely affecting germination, crop vigor, and crop yield. **[21]**. Salinity-induced negative consequences on plant growth and development include cytotoxicity caused due to unwarranted absorption of ions like sodium (Na^+) and chloride (Cl^-) and nutritional imbalance. In addition, salinity leads to oxidative stress due to the production of ROS (reactive oxygen species) **[22]**. Water stress, nutritional disorders, ion toxicity, alteration of metabolic processes, oxidative stress, cell division and expansion drop, membrane disorganization, and genotoxicity are essential ways salinity can affect plant growth and development **[23]**. Reduced leaf growth caused by water stress is the first sign of salt stress. As the salinity phase lengthens, plants become more susceptible to early senescence, which reduces the photosynthetic surface **[24]**. Reduced cell development, division, and stomatal closure result from salinity stress-induced osmotic effects that appear right after salt exposure and are thought to last for the period of the exposure **[25]**.

iv. Heat stress

When temperature rises and the climate becomes hot enough for an extended time, plants are subject to heat stress. The heat stress effects on how different plant components operate and grow are irreversible. Crop production and global food security are negatively impacted by heat stress, making it one of the most detrimental abiotic stresses that agricultural plants face [26]. Crop yields decrease by 10–17% for every 1°C rise in seasonal temperature. High daytime and nighttime temperatures, high soil temperatures, or a combination of heat intensity, exposure length, and the pace of temperature rise are only a few of the causes of heat stress **[27]**. The rising atmospheric CO_2 concentration and other greenhouse gases, according to the IPCC report from 2022, would cause future temperatures to rise along with unfavorable changes in rainfall patterns. Studies have shown that, in addition to rising annual mean temperatures, the frequency, duration, and severity of extreme heat events are also on the rise **[28]**. Thus, plants will likely be subjected to more acute heat stress and higher mean temperatures. Crop yields may be significantly impacted by heat stress' negative impacts on root growth and plants' reduced photosynthetic and transpirational efficiency.

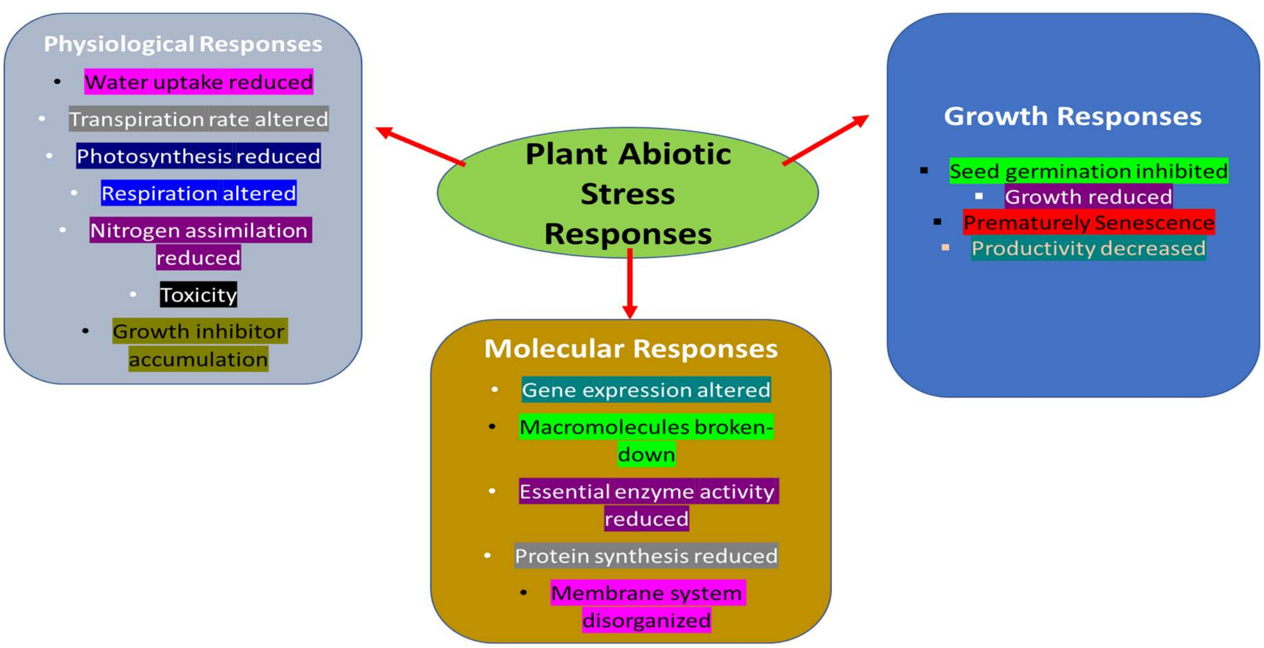

Figure 2: Abiotic stress responses of plants (Common beans)

3. Common bean breeding goals for abiotic stress tolerance

Plants adapt to various abiotic pressures through several characteristics like water absorption efficiency, carbohydrate reserve storage, and mobilization, root hydraulic conductivity, root length and growth, and plant phenology, demonstrating their resilience in facing these challenges **[29]**. Plant breeders and physiologists may improve the numerous features currently existing in the plant system, but they are especially interested in traits related to metabolizing photosynthates from green plant sections to the seed and pod walls under water stress **[20]**. Although common beans are vulnerable to water stress (drought), features associated with the mobilization of photosynthates, such as the harvest index (HI), pod partitioning index (PPI), and pod harvest index **[30]**, may be utilized for drought-adapted bean selection like those of Durango race, tepary bean and some drought resistant lineages from Africa **[20, 29, 31, 32]**. As several traits are involved in resistance mechanisms, the traits are quantitatively inherited, and the environment substantially affects the traits, breeding for more significant drought adaption is challenging **[33]**. By employing Random Amplified Polymorphic DNA (RAPD) markers to differentiate drought-related QTLs, the potential of marker-aided selection (MAS) for enhancing drought resistance can be investigated **[34]**. Genotypes of environmental relationships influencing drought QTL have been found by A Asfaw and MW Blair [31] and B Briñez, J Perseguini, JS Rosa, D Bassi, JGR Gonçalves, C Almeida, JFC Paulino, MW Blair, AF Chioratto, SAM Carbonell, *et al*. **[35]**. A Asfaw and MW Blair **[31]** also reported that QTLs explain up to 37% of the phenotypic variation for SPAD leaf chlorophyll and pod partitioning index characteristics. This study demonstrates the significance of QTL identification for photosynthate acquisition and remobilization traits. The QTLs identified may be helpful for MAS in bean breeding programs to indirectly select drought-tolerant characteristics that are difficult to screen in large populations.

Bean output is significantly limited by high temperature (HT) stress **[36, 37]**. HT (greater than 30 °C day and more than 20 °C night) correlates to a significant decrease in production and quality and hinders environmental adaptability. High temperature impacts pollen fertility, lowers bloom, and results in declined quantity and quality of seeds. Heat-tolerant common bean genotypes from distinct gene pools have been identified [38]. Common beans may maintain pollen viability at nighttime temperatures up to 5 °C greater than those that are often thought to be limiting (> 18 °C). The development of heat-tolerant plants in harsh conditions would also boost resilience to future climate change challenges **[39]**.

Due to their sensitivity to cold temperatures, common beans' early-season productivity is limited. Variations between genotypes with inadequate temperature tolerance were documented by M Dickson and M Boettger **[40]**. Common beans' earliest trifoliate and unifoliate leaf stages are the most vulnerable to cold conditions **[41]**. Incorporating genetic material from the tepary bean into the common bean genome is a practical way to boost the latter's heat tolerance **[42]**.

Traits/Indices for breeding to abiotic stress tolerance in common beans

Cold stress	Moisture stress	Salinity stress	Heat stress
Stomatal density	Root length	Ion homeostasis	Leaf cooling
Stomatal index and pattern	Root biomass	Ion uptake and transport	Water potential
Chlorophyll fluorescence	Root diameter	Synthesis of polyamines	Canopy temperature
Protein content	Later roots	Accumulation of carbohydrates and sugars	Photosynthetic efficiency
	Shoot biomass	Root mass	Heat stress index
	Leaf area		Heat susceptibility index
	Pod harvest index		
	Root/Shoot ratio		

4. Mechanisms for mitigating abiotic stresses in common beans

i. Cold tolerance

Different physiochemical changes brought on by exposure to cold stress impede the growth and development of common beans. Specific transcription factors are activated in response to cold stress in plants, and these genes and transcription factors assist plants in building tolerance by reducing the damage brought on by cold stress. Many enzymes and membrane metabolite transporters experience changes in their structure, catalytic ability, and behavior when exposed to temperature stress **[43]**. Plant regulatory systems are responsible for restoring normal metabolite levels and, more crucially, metabolic fluxes **[44]**. Also, the mechanisms of increased tolerance are principally related to metabolic improvements in response to temperature stress. Long-established relationships exist between stress responses and several metabolites with important characteristics that may induce stress resistance **[45]**. In several instances, osmolyte-functioning metabolites have attracted special attention. Osmolytes are important in regulating cellular water relationships and preventing cellular dehydration. Psychrotolerant bacteria obtained from wild cold-tolerant plants confer cold tolerance in beans by reducing ROS levels and lipid peroxidation, freezing injury, and ice nucleating activity **[46]**.

ii. Drought tolerance

Common beans' complex drought tolerance trait involves numerous regulated genes influenced by the environment and relies on various morphological and physiological traits **[29]**. Many characteristics, including a deep root system, a buildup of biomass, the transfer of stored biomass to the seed, and the harvest index, are responsible for grain output stability during water scarcity **[47]**. According to SE Beebe, IM Rao, MW Blair and JA Acosta-Gallegos **[29]**, the contribution of several physiological parameters, like transpiration rate, leaf water potential, leaf temperature, chlorophyll content, photosynthetic efficiency, and stomatal conductance, is what gives common beans their resilience to drought. Solute accumulation has been discovered as another crucial property of the process of drought adaptation in addition to these morphological and physiological properties **[48]**. Plants build up a variety of osmoprotective solutes in response to abiotic stresses, including amino acids, sugars, alcohols, and quaternary ammonium compounds. This causes cells to become dehydrated, which reduces the osmotic potential of cell membranes and the stability of proteins and membranes in plants [11]. Many species have indicated that proline and glycine are essential strategies for plants to adapt to dry conditions **[49]**.

iii. Salinity tolerance

Plants have evolved several biochemical methods to thrive in soils with high salt concentrations. The main defenses against salinity stress include ion transport and absorption, compatible solute biosynthesis, ion compartmentalization and homeostasis, antioxidant synthesis and activation, nitric oxide (NO) production, polyamine synthesis, and hormone regulation. In response to salt stress, plants utilize a wide range of mechanisms to modulate (raise or reduce) certain gene expressions and establish different gene control mechanisms at transcriptional, translation, and post-translational protein modification levels during salt stress plant response **[50].**

iv. Heat tolerance

Heat tolerance is a plant's capacity to thrive and produce economic harvests despite high temperatures **[51]**. Certain plants resist heat stress at higher temperatures by conserving the efficacy of photosynthesis via the regulation of stomatal conductance **[52]**. Maintaining open stomata at high temperatures increases transpirational cooling and promotes CO_2 diffusion in the leaves **[53]**. Consequently, plants able to sustain stomatal conductance at high temperatures can better regulate their internal temperature. Common beans have a good heat reduction approach, including leaf cooling **[54]**.

5. Proline- As an abiotic stress biomarker in Common beans

One of the most prevalent plant osmolytes, proline, may be a good candidate for abiotic stress detection since it has been shown that beans significantly increase their proline content in response to water stress, salinity stress, and other stressful situations. Nevertheless, due to conflicting data in the literature, proline accumulation is connected to either an enhanced or reduced stress tolerance in common beans, which is yet to be deciphered. While greater proline concentrations were observed in some instances in the substantially more stress-sensitive cultivars, other research connected higher proline content with a relatively better stress tolerance compared to various bean cultivars **[55, 56]**. Comparing a few genotypes was the foundation for both investigations. Only a broader analysis, based on a much larger number of cultivars grown under the same experimental circumstances and exposed to the same stress treatment, can clarify whether proline accumulation-based stress response is necessary for stress tolerance in common beans and how proline may be employed as a biomarker for stress treatment in common beans.

CONCLUSION

The reality that different abiotic stressors will continue to hinder agricultural plants like common beans (*Phaseolus vulgaris* L.) from growing and producing in the future is difficult to accept. To lessen these abiotic stressors' enduring impact on agricultural plants, breeders should create types that are resistant to them in the future. For developing diverse mechanisms for abiotic stress tolerance, it is necessary to discover the features that plants already have that make them resistant to these abiotic stresses. Developing resistant cultivars tailored to certain agroclimatic conditions can also help solve such issues.

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