
Biotic and Abiotic Stress in Common Bean
(*Phaseolus vulgaris* L.)

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1. INTRODUCTION

Over the past few years, the food chain has grown and changed quickly. Also, it has become easier to get refined, high-fat foods. This is primarily because of improvements in industrial processing and the ability to move goods over long distances (Albuquerque et al. 2022). Because of this, people eat less local and seasonal foods, especially those high in fiber, and more heavily processed foods high in refined starch, sugar, saturated fat, and salt (Monteiro et al. 2019; Albuquerque et al. 2022). As food production practices intensify, people in high-income countries are eating more high-calorie, animal-based foods. This is worsening the environment and using natural resources faster (Swinburn et al. 2011; Westhoek et al. 2014). By 2050, the world's population is expected to double, which raises serious concerns about food security. Even though much food is made for the world's population, serious and harmful nutritional deficiencies exist worldwide. Certain parts of the world are starting to see high rates of obesity, overeating, and nutritional deficiencies caused by diseases that can't be spread from person to person. On the other hand, in some areas, the number of people without enough food is increasing, which could lead to big problems (Clapp 2018; Rahut et al. 2022). Many people worldwide suffer from 'hidden hunger', a type of nutritional deficiency that keeps them from living a healthy life because they don't get enough micronutrients (von Grebmer et al. 2014; Temba et al. 2016). People think a sustainable diet is a meaningful way to make the world's food system healthier. This could be one of people's most important and urgent problems (Springmann et al. 2018; Willett et al. 2019; Pörtner et al. 2023).

Beans are known for feeding more than 300 million people and being important to agricultural economies worldwide (Uebersax et al. 2023). Beans are legumes that are generally consumed dried but are also consumed fresh in small amounts in their shells (Rawal and Navarro 2019). The amount of dry beans grown has gone up by about 60% since

the early 1990s, and the amount of land used to produce them has gone up by 36% in the same time (Rawal and Navarro 2019; Uebersax et al. 2023). Asia is the world's largest producer of dry beans, making up about 43% of the total. Next, the Americas comprise about 29% of the total, and Africa constitutes 26% (Uebersax et al. 2023). All common plants grown on different continents have a long history of breeding and evolution. They can be traced back to wild plants like *Phaseolus vulgaris* var. *aborgines* and *Phaseolus vulgaris* var. *mexicanus*, native to the Americas (Rodiño and Drevon 2004). Beans are a valuable global resource for biodiversity because they have landraces grown in different ways in different cultures, which adds to genetic diversity (Uebersax et al. 2023). In this book chapter, information is given about the bean plant's biochemical, physiological, morphological, and molecular response mechanisms under biotic and abiotic stress conditions.

2. ABIOTIC STRESSES in COMMON BEAN

2.1. Drought Stress

Drought stress has become a significant problem in recent years, significantly affecting the global food supply (Budak et al. 2013). Legume-producing regions worldwide, such as common beans, experience moderate to severe drought conditions. It is thought that drought stress caused by drier weather conditions following climate change will increasingly affect bean production (Mohammed and Feleke 2022). It is predicted that drought will be a significant problem in the coming years, and crops may experience prolonged and severe drought. However, increasing drought tolerance in bean varieties can significantly increase production levels and yields (Broughton et al. 2003; Ghanbari et al. 2013; Asfaw et al. 2014). Research indicates that bean yields experiencing drought stress during the flowering and post-flowering

stages are diminished by 60-99% (Manjeru et al. 2007; Ambachew et al. 2015). Drought stress can often lead to reduced osmotic pressure and storage of water potential in the plant's capacity. This condition mainly causes oxidative stress and cellular damage, affecting photosynthesis, carbon fixation, and primary metabolism. As a result, crop yields and survival rates decrease significantly. Current breeding efforts concentrate on identifying physiological markers that correlate with enhanced phenotypic traits in plants subjected to drought conditions (Lizana et al. 2006; Mladenov et al. 2023).

Drought stress significantly affects hormones, the movement of stored substances, and the structure of proteins. This, in turn, makes it harder for seeds to germinate and plants to grow (Basal et al. 2020). When plants are stressed by drought, reactive oxygen species (ROS) build up in their cells. This buildup causes oxidative damage, which can change the shape of proteins and break down cell membranes (Bahadur et al. 2019). This process can severely disrupt the structural integrity of membranes, proteins, and DNA (Qari et al. 2022; Rehman et al. 2022). Working on making plants more drought-resistant in safe and cost-effective ways is very important. There are now many ways to deal with the problems that drought stress causes, such as utilizing superabsorbent moisture, adding mycorrhizal fungi, applying nanoparticles, and breeding plants that can handle drought (Fadiji et al. 2022).

Mycorrhizal fungi play an important role in the ecosystems as they can colonize the roots of approximately 80% of plant species. This partnership has several benefits, such as better plant growth, more nutrients, stronger roots, more flowers, and more resistance to stress (Pozo et al. 2015). More research on common bean and other legumes shows that mycorrhizal symbiosis is important in making plants more resistant to drought (Recchia et al. 2018; Hashem et al. 2019).

Nanofertilizer is an important part of farming that has caught the attention of both soil and environmental scientists. It can boost crop yields, make soil more fertile, reduce pollution, and improve the environment for microorganisms (Ahmadian et al. 2021). Utilizing chemical fertilizers can be very expensive for farmers and bad for people's health and the environment. So, nanofertilizers might help plants deal with abiotic stress better (Astaneh et al. 2021; Márquez-Prieto et al. 2022; Salama et al. 2022).

Seed priming is an effective and cost-efficient method that enhances drought stress tolerance by facilitating better seed germination (Sadeghipour et al. 2018; Marthandan et al. 2020). When hydrogen peroxide (H_2O_2) is in low concentrations, it acts as a secondary messenger and helps plants deal with stress (You and Chan 2015; Farooq et al. 2017).

Gene activation and regulation of gene expression control the many changes in shape, function, and chemistry that happen when there is a drought. *MYB*, *WRKY*, *DREB*, and *NAC* are transcription factors that are very important in shaping these responses (Recchia et al. 2013; Wu et al. 2016; Wu et al. 2017; López et al. 2020). In general, osmoprotection means coordinating the transcription of genes, which is important for controlling hormones and stomata (Liu et al. 2020).

Aquaporins (*AQPs*) are a group of genes that are very important because aquaporin proteins help move water across cell membranes. In drought-stressed beans, higher expression levels of *AQP* genes in the roots and leaves have been shown to help the plants hold onto water and lose less water through transpiration (Aroca and Ruiz-Lozano 2012; Zupin et al. 2017). The results show how important aquaporins are in keeping cells hydrated, especially when there isn't much water. Researchers also found important proteins for taking in and moving water and ions. These include aquaporins, RING-type E3 ubiquitin

transferases, and antioxidant enzymes such as glutathione S-transferase (GSTs) and Cytochrome P450 (CYPs), and thioredoxins (TRX) (Ponce et al. 2024).

2.2. Salinity Stress

Salt stress is the second most important abiotic stress after drought stress. It greatly affects how well crops grow (Mosa et al. 2017). Soil salinity is caused by high salt levels in the soil, which can impair crop growth and even kill plants. Salt buildup in farm soil can change how plants work in many ways. Soil salinity can affect everything from seed germination to growth, flowering, and fruit set. This can then affect productivity (Mbarki et al. 2020).

Biostimulants, nature's subtle but powerful helpers, are essential to modern farming, especially when reducing salt stress's destructive effects on legumes. These resources encompass diverse substances, including compounds from biological origins, seaweed extracts, humic acids, and microbial inoculants. Each has biochemical properties that help plants grow, develop, and fight off disease (Johnson et al. 2024). Biostimulants are crucial in managing osmotic imbalance, ion toxicity, and oxidative damage from salt stress in plants. Their participation in osmotic regulation is vital because they regulate the accumulation of compatible solutes such as proline and glycine betaine. For example, these solutes are essential for maintaining cellular turgor and facilitating water uptake in mung bean (Kumawat et al. 2021). Biostimulants also make the plant's antioxidant defenses stronger, which helps it fight off reactive oxygen species. This neutralization stops oxidative damage to cell structures (Hasanuzzaman et al. 2021). When legumes are under stress, they use biostimulants to improve their relationship with nitrogen-fixing root bacteria. This support helps with nodulation, fixes nitrogen, and helps plants absorb nutrients (Dubey et al. 2020). Biostimulants

work in complex ways to boost the plant's natural defense systems, which makes it better able to handle and adapt to salt stress.

Microbial biostimulants, like nitrogen-fixing bacteria (NFB), are essential for controlling the levels of ethylene, cytokinin, ABA (abscisic acid), and GA (gibberellic acid). These levels help maintain many physiological activities (Sofy et al. 2021). Recent studies indicate that NFB may enhance the activity of ROS-scavenging enzymes, such as catalase (CAT), superoxide dismutase (SOD), and peroxidases (POD). This rise strengthens the faba bean's antioxidant defense system (Hafez et al. 2021).

The presence of varying salt concentrations has led to reduced growth in legumes. Salt stress negatively affects nodulation in legume plants by disrupting initial symbiotic interactions. Legume plants co-inoculated with bacterial biostimulant strains of *Rhizobium* and *Pseudomonas* exhibited a reduction in salt stress, which in turn increased colonization of root tips (Egamberdieva et al. 2013). Plant growth-promoting bacterial biostimulants bind to legume roots and promote root elongation by reducing ethylene levels. (Shaharoona et al. 2006). Another study highlighted the role of the plant growth-promoting bacterial biostimulant *Bacillus cereus*, known for its production of ACC-deaminase, siderophores, and IAA (indole-3-acetic acid), and its ability to solubilize phosphate. This biostimulant has reduced high ethylene levels under salinity stress conditions (Kothari and Manuel 2015). Developing salt-tolerant symbiosis is essential to enhance crop growth in saline soils. Inoculation of soybean plants with plant growth-promoting bacterial biostimulants, particularly *Bradyrhizobium japonicum* strains, has been observed to enhance plant growth, photosynthesis, and nutrient uptake, particularly under salt stress conditions (Han and Lee 2005).

2.3. Molecular Mechanisms Developed Against Stress in Beans

Plants possess sophisticated response mechanisms against pathogens. These response mechanisms are closely linked to the evolution of the centuries-long plant-pathogen association. Key molecular responses include the production of phenolic compounds, changes in peroxidase metabolism, Type III secretion, blockage of vascular tissues, lignin production, and the restriction of pathogen-infected tissues, as well as mechanisms such as apoptosis. Phenolic compounds are the names given to certain compounds that are produced primarily as secondary metabolites in plants. Phenolic compounds rapidly increase at the tissue level during pathogen spread. Similarly, peroxidase enzymes can also play a role in polymerization, promoting cell wall thickening. Bacterial and viral infections, particularly, activate plants' Type III secretion system. This secretion system also causes hormonal changes, activating plant defense systems. Oligomers called NOD-like receptors (NLRs) have been identified in some bean genotypes. It has been determined that these receptors, upon recognition of the infectious agent, activate the caspases responsible for infection, causing a hypersensitive response (HR) (Franchi et al. 2009). As a result of this hypersensitive response, necrotic lesions, senescence, and even apoptosis can occur in plant leaves.

In addition to all this, plant infection elicits several tissue-level responses. These responses are generally observed in the leaves and stems. However, if the plant fails in this control, these responses can also be seen in the roots and flowers. The most obvious examples of tissue-level responses include the plant limiting the spread of the pathogen by killing the infected area through programmed cell death and deliberately blocking the vascular tissues, preventing the pathogen from spreading into the plant through interstitial fluids. These are accompanied by the detachment of the entire leaf from the plant, a phenomenon particularly

seen in fungal infections. In fact, increasing peroxide levels following Type III secretion cause immediate tissue-level responses. Concomitantly, increases in salicylic acid levels have been recorded (Duncan et al. 2011; Chen et al. 2021). This activates MAPK signaling pathways, and the plant attempts to interrupt the pathogen's interaction with its nutrient sources and environment.

In addition, Makhumbila et al. (2025) investigated the responses to bean rust using a resistant (Teebus-RR-1) and a susceptible (Golden Gate Wax) bean cultivar. A total of 3175 differentially expressed genes (DEGs) were identified in this study. The resistant cultivar (Teebus-RR-1) contained 88% of these genes (2806), while the susceptible cultivar contained only 369 DEGs. In plants, early and late responses were obtained through RNA-seq analyses performed on days 14 and 21. The studies revealed that heat shock proteins, receptor-like kinases (CRK29), cytochrome P450 enzymes, and terpene synthesis enzymes were activated in the early stage, initiating defense. In the late stage (day 21), a stronger stress response and enhanced photosynthetic cultivar were observed, while increased secondary metabolite levels and activation of general defense pathways were observed in the susceptible cultivar. However, insufficient defense success was noted in susceptible cultivars. This study revealed that the defense proteins of RPS2, CAR1, and DM2H are associated with this disease. Its agriculturally significant contribution is the discovery of new biomarkers using RNA-seq for marker-assisted breeding. The primary contribution of such studies is the development of durable resistance to specific diseases (Makhumbila et al. 2025).

Specific transcription factors, such as MYB, bZIP, bHLH, WRKY, NAC, ERF, and DREB, have been shown to function as key regulators of signal transduction pathways in plant drought tolerance (Singh et al. 2015). Furthermore, various functional proteins, such as aquaporin (Wu

et al. 2022), late embryogenesis abundant (LEA) proteins (Jia et al. 2022), and heat shock proteins (ALH) (Zhou et al. 2016), have also attracted attention. New research suggests that ncRNAs and protein-coding RNAs may play important regulatory roles in plant responses to drought stress (Gelaw and Sanan-Mishra 2021; Thanmalagan et al. 2022). Earlier research has demonstrated that miR159, miR160, miR167, miR169, and miR393 influence the drought resistance of tomatoes by regulating hormone signaling, stomatal closure, and auxin-responsive genes (Rao et al. 2020; Zhou et al. 2020b). In common bean (*Phaseolus vulgaris*), legume-specific miR1514a, miR2119, and a conserved miR2118 were upregulated with a concomitant decrease of their targets, such as superoxide dismutase (MnSOD) and cysteine protease, ADH1, and APS reductase, respectively (Arenas-Huertero et al. 2009; Chatterjee et al. 2025).

Recent improvements in high-throughput methods for analyzing gene expression profiles have made it easier to understand how plants react to abiotic and biotic stressors (Qing et al. 2009; Xu et al. 2013). There has been a notable increase in research employing RNA sequencing data and expression profiling in model plants and essential crops to identify the genes involved in stress responses (Ge et al. 2010; Postnikova et al. 2013). Next-generation RNA sequencing analyses will use continuously generated reference genome sequences for different legume species to help find and clone stress tolerance genes and make new varieties with better tolerance mechanisms (Schmutz et al. 2010; Young et al. 2011; Goodstein et al. 2012; Varshney et al. 2013).

2.4. Heavy Metal Stress

Heavy metals (HMs) are used for metals with a specific gravity greater than 5 g/cm³ (Järup 2003; Bothe 2011). HMs are among the most dangerous and polluting elements for all living organisms. Excessive accumulation of HMs such as cadmium (Cd), lead (Pb), and mercury (Hg) causes permanent damage to plants. In response, plants try to show tolerance by providing intracellular and extracellular sequestration (Kosakivska et al. 2021). HM stress is one of the most damaging abiotic factors affecting plant quality and yield, resulting in death. Adverse effects such as oxidative stress, damage to cell membrane permeability, and disruption of the photosynthetic mechanism may occur due to increased production of reactive oxygen radicals in plants exposed to HMs (Feng et al. 2021). HMs are released into soil as a result of natural processes or industrial activities, excessive fertilization, use of wastewater for irrigation, and other anthropogenic activities and cause adverse effects on plants due to their solubility in water and lack of biodegradability (Başdinç and Çirka 2021; Khatun et al. 2022; Kiran et al. 2022; Sharma et al. 2022).

P. vulgaris is one of the primary food sources preferred for good nutrition due to its high fiber, protein, and low-fat content (He et al. 2018). However, it has been observed that *P. vulgaris* metabolizes HMs and negatively affects plant growth stages, disrupting growth and development processes (Çelik and Nadaroglu 2018; Silva-Gigante et al. 2023). It has been found that HMs inhibit water and element uptake and nitrogenase activity in beans and reduce the number of nodules by disrupting the nodule structure (Hammami et al. 2022).

Changes such as chlorophyll content, enzyme production, growth and development rate, and leaf and root area are examined as indicators of plant responses to HM stress (Farid et al. 2013). HMs are transported into plants via roots, and heavy metal concentrations in roots are often

higher than in shoots (Małkowski et al. 2019). As a result of Cd and Pb treatment, heavy metal content in *P. vulgaris* roots was higher than in other plant organs (Cannata et al. 2015). Copper (Cu) and zinc (Zn) treatments also resulted in greater accumulation of heavy metals in *P. vulgaris* roots than in shoots (Urwat et al. 2021; Younis et al. 2018a). As a result, when the morphological effects of HMs are examined, more damaging effects occur on the roots. In common bean treated with 200 mg/kg Cd, a decrease of 53.07% and 54.35% in root fresh and dry weights, respectively, occurred compared to the control, and this decrease was found to have the highest reduction rate compared to other parts of the plant (Dadasoglu et al. 2022). Cd, which enters plants through carriers such as Ca^{2+} , Fe^{2+} , Mn^{2+} , and Zn^{2+} , negatively affects plant development (Verbruggen et al. 2009; Liu et al. 2025). More Cd accumulation occurred in *P. vulgaris* roots exposed to Cd stress compared to shoots (Bahmani et al. 2020). Similarly, increasing Cd doses decreased leaf number and leaf area (Yildirim et al. 2023). When examining plant physiological responses to HMs, one of the critical indicators is photosynthetic performance (Chen et al. 2019). It is known that Fe (III) reductase is inhibited in plants exposed to Cd, and Fe (II) deficiency occurs, causing photosynthesis to be negatively affected (Alcántara et al. 1994). The decrease in photosynthetic pigment contents in *P. vulgaris* under Cd stress at 0.25 μM , 0.5 μM , and one μM concentrations also occurred as a result of these effects (Beatriz Gutiérrez-Martínez et al. 2024). Another effect is that HMs affect water intake, causing water imbalance (AbdElgawad et al. 2020). It was observed that the water content decreased as the application dose increased in common beans exposed to Pb stress (Kul et al. 2019). In addition, HMs disrupt protein homeostasis by interfering with protein folding processes and lead to loss of cell viability (Hasan et al. 2017). While the arsenate [As (V): AsO_4^{3-}] form enters plants with the help of phosphate carriers, it disrupts phosphate metabolism, the As (III) form

binds to sulfhydryl groups and causes degradation of the protein structure (Su et al. 2010; Silva-Gigante et al. 2023). It was determined that the soluble protein content in *P. vulgaris* decreased after 2 and 5 mg As application compared to the control group (Stoeva et al. 2005). Similarly, it was determined that the total protein content in *P. vulgaris* exposed to Pb stress for 1 week decreased due to increasing heavy metal concentration (Hamid et al. 2010). One of the biochemical responses that plants give when exposed to HM stress is lipid peroxidation (MDA) due to membrane damage. It was determined that MDA content in *P. vulgaris* under Cu and Cd stresses increased as a response to HM (Younis et al. 2018b). Another biochemical change is the production of reactive oxygen species (ROS). Enzymatic antioxidants such as SOD, POD, CAT, APX, DHAR, and MDHAR, as well as non-enzymatic antioxidants such as ASA, GSH, carotenoids, and tocopherols, are involved in the detoxification of these ROS (Arif et al. 2016; Raza et al. 2021). Both enzymatic and non-enzymatic antioxidants increased *P. vulgaris* growth with wastewater and exposed to heavy metals such as Cd, Co, Ni, and Pb (Nowwar et al. 2023).

Phytohormones such as abscisic acid (ABA) and indole acetic acid (IAA) act as signal molecules in the removal of ROS and trigger the production of antioxidant enzyme system elements (Emamverdian et al. 2020). In common bean under Cd stress, the expression of *ABA 8'-hydroxylase* and *IAA* genes, which regulate ABA degradation, increased due to stress (Ekinici et al. 2023). In addition, plants can control events such as the uptake and detoxification of HMs by regulating gene expression through transcription factors such as heat shock protein (HSF) and basic leucine zipper (bZIP) (Li et al. 2022b). It was determined that the expression of *HSF* gene family members changed due to Cd and Hg treatment, and the expression of bZIP gene family members changed due to Zn treatment (Astudillo et al. 2013; Zhang et al. 2022). In addition, transporters such as natural resistance-associated

macrophage protein (NRAMP) in HM transport are one of the critical genes responsible for the accumulation of HMs in plants (Kanwal et al. 2024). The increase in *NRAMP* gene expression after 300 μM Zn treatment in common bean confirms that it plays a role in this transport (Urwat et al. 2021). Moreover, microRNAs (miRNAs) and their targets that regulate gene expression in plant tolerance to HM stress should not be ignored (Noman and Aqeel 2017). It was found that overexpressed miR1511 in aluminum (Al) treated common bean suppressed its target, aluminum-responsive 3 protein (ALS3). As a result, the plant became more sensitive to Al stress (Ángel Martín-Rodríguez et al. 2021). These results indicate that the plant tries to gain tolerance to stress by regulating gene expressions for resistance to HM stress.

Various strategies have been developed to mitigate the damaging effects of HM on plants. One of these strategies is using exogenous applications of phytohormones (Saini et al. 2021). One of these phytohormones is gibberellic acid (GA3). GA3 applied exogenously to common beans under Cd and Pb stress was found to have a healing effect by reducing HM toxicity (Dilek Tepe 2022). Exogenous application of salicylic acid (SA), another phytohormone, increased antioxidant and proline activities in common bean under Cd, Ni, and Pb stress (Hediji et al. 2021; Khalil et al. 2021). Similar effects were observed after applying jasmonic acid (JA) (Hashem and El-Sherif 2019). Another strategy is using polyamines as antioxidant enzyme activators (Malik et al. 2022). Exogenous application of spermine, a polyamine used to alleviate the adverse effects of As (III) and As (V) forms on common bean, increased the expression of antioxidant enzyme activity and zinc finger protein-related genes involved in stress responses (Shah et al. 2022). Another strategy is nanoparticles (NPs), which are preferred due to their ability to penetrate a large area of plants and their contribution to ROS scavenging and plant growth and development stages (Zhou et al. 2020a; Faizan et al. 2023). For this purpose, biological silicon NPs used for

common beans in HM soil were found to affect protecting plant health against stress by increasing antioxidant enzyme activity (El-Saadony et al. 2021). Similarly, iron oxide NP (IONP), zinc oxide NP (ZnO NP), and copper oxide NP (CuO NP) applications also increased the stress tolerance of common bean under Cd stress (Hidouri et al. 2022; Koleva et al. 2022).

HMs are one of the abiotic stress factors that negatively affect common bean development and yield. HMs such as As, Cd, Ni, and Pb, which mix with the soil through anthropogenic and non-anthropogenic means, enter the plant through the roots and cause permanent damage to the morphological and physiological systems. Plants try to provide tolerance to stress by responding to these damages through various defense mechanisms. This tolerance is achieved through antioxidant enzyme systems, the synthesis of metal transporters, and their regulation by compounds such as phytohormones, transcription factors, and miRNA. The elucidation of HM stress responses and tolerant mechanisms of common beans will facilitate the selection of varieties that are resistant to this stress. In addition to the plant's own tolerance, exogenous phytohormone, polyamine, and nanoparticle applications are also used to help the plant's tolerance. Different applications applied to common beans and the determination of the underlying mechanism of these applications will contribute to the development of common bean varieties resistant to HM stress in the future.

2.5. Cold and Heat Stress

Due to extreme weather events and global climate change, plants are increasingly exposed to temperature changes. This causes temperature stress, which includes both cold and heat stress. From a food security perspective, heat stress reduces plant production and impacts crop yields. Furthermore, temperature changes negatively impact the distribution of plants worldwide (Ding and Yang 2022).

Heat stress is categorized into three classes based on stressors: high, chilling, and freezing temperatures. High heat stress refers to temperatures above 27°C. Chilling temperatures are between 0°C and 15°C, and freezing temperatures are below 0°C. Because temperature is a physical signal, it is quickly sensed by the nucleus or cell membrane in the plant cell. Plants respond soon to heat stress by developing molecular strategies such as proteins, metabolites, antioxidants, membrane lipids, and regulatory factors (Kai and Iba 2014; Ding and Yang 2022; Yang et al. 2023). On the other hand, cold stress can inhibit growth because it affects enzyme activity (Zhang et al. 2020). In addition, plants inhibit photosynthesis, and cell membranes undergo lipid peroxidation (Ali et al. 2025; Cheng et al. 2025). Therefore, elucidating the molecular mechanisms that play a role in plant adaptation to heat and cold stress is essential and helps agricultural production.

Recently, attempts have been made to elucidate the molecular mechanisms underlying heat stress. When plants perceive heat stress, heat-responsive genes are activated, and these genes are regulated at both the transcriptional and post-transcriptional levels. Expression of cold-responsive (COR) and heat-responsive genes is activated by transcriptional factors such as CBF/DREB1 (C-repeat binding factor/Dehydration responsive element binding 1) and HsfA1 (heat shock factor A1), respectively (Li et al. 2022a; Wang et al. 2022).

Cold and heat signal perception occurs through Ca^{2+} and ROS signals and regulation of gene expression, protein activities, and protein homeostasis (Wang et al. 2022). The cell membrane is the first line of defense against heat stress. Another important organelle is the nucleus (Ding et al. 2019). Both cold and heat stresses can cause changes in the fluidity of cellular phospholipid membranes (Dutta et al. 2025; Su et al. 2025). This change is sensed by channels, various transporters, and integral membrane proteins such as membrane-anchored receptor-like

kinases (RLKs). Heat stress is sensed by molecular chaperones (Zhu 2016). Histidine kinases such as Ethylene Response 1 (ETR1), Arabidopsis Histidine Kinase 2 (AHK2), and AHK3 are associated with cold stress (Nongpiur et al. 2012; Zhang et al. 2025).

Various ion channels are located in the plasma membrane as heat sensors. COLD1 (Chilling-tolerance divergence 1), a protein located in the plasma membrane and endoplasmic reticulum in plants, forms a complex with RGA1 (G-protein α -subunit 1) in the plasma membrane, which promotes Ca^{2+} entry into the cell for cold sensing in rice (Zhu 2016). The role of COD1 in heat stress, however, is not fully elucidated (Ding and Yang 2022).

Several nuclear proteins, such as UVR (UV resistance locus 8), PHOTS (phototropins), CRYs (cryptochromes), and phytochromes (photoreceptors), along with members of the ZEITLUPE family (ZTL, FKF1, and LKP2), play essential roles in heat sensing. These proteins are responsible for the reception of UV-A, UV-B, red, and blue light (Bian et al. 2022). phyB, a thermosensor, is found in the cytosol and nucleus. Depending on temperature, phyB transitions from an active to an inactive state. phyB releases the inhibition of the transcription factor PIF4 (phytochrome-interacting factor 4). High ambient temperatures cause thermomorphogenesis, which leads to rapid plant growth and morphological changes (Fan et al. 2025). Similarly, phyB increases plant freezing tolerance through the PIF3-CBF interaction (Das et al. 2025; Xu et al. 2025). PIF1, PIF4, and PIF5, negative regulators of cold stress, are degraded by phyB, which is stabilized by cold treatment. Thus, plants improve their tolerance to cold (Bian et al. 2022). UVR8 responds to cold stress by converting from an inactive dimer to an active monomer, contrary to UV-B, resulting in a decreased thermomorphogenic response (Hwang et al. 2025).

Low and high temperature stresses are important abiotic stresses for bean plants (Srivastava et al. 2015; Vargas et al. 2021). Studies on beans under heat stress were evaluated with molecular, biochemical, morphological, and physiological parameters. In their study investigating the effect of cold stress occurring during the flowering period on reproduction, Gobatto et al. (2025) determined that cold stress had an adverse impact on yield components by extending the growth cycle of bean genotypes in the field and caused a decrease in yield. Also, low superoxide dismutase enzyme activity was reported to be associated with greater cold tolerance. On the other hand, in a study in which both transcriptomic and metabolomic methods determined the effects of cold stress on common bean, it was defined that the genes induced under chilling stress were involved in lipid, amino acid, and flavonoid metabolisms. Malondialdehyde (MDA) content, amino acid concentration, methionine accumulation, and flavonoid content differed between cold-tolerant and susceptible genotypes. It was also suggested that flavonoids, MDA, and methionine could be biomarkers for plant chilling injury. According to the transcriptomic analysis of hormone metabolism, it has been determined that the expression levels of genes responsible for gibberellin (GA), abscisic acid (ABA), and jasmonic acid (JA) synthesis differ among genotypes during chilling stress (Yang et al. 2023). A study investigating the effects of exogenous acetylsalicylic acid (ASA) on cold stress found that ASA treatment positively improved physiological and biochemical parameters such as carotenoid concentrations, total soluble proteins, electrical conductivity, photosynthesis, antioxidant enzyme activity, and malondialdehyde. A positive correlation was identified between antioxidant enzymes and photosynthetic activity. Additionally, it was reported that expression levels of antioxidant genes such as *APX1*, *POD1*, and *SODC*, and photosynthesis genes such as *RbcS1*, *PsbS*, and *POR* were increased, suggesting that these genes may be important in reducing cold-induced

oxidative stress and preserving chloroplast functions (Ali et al. 2025). Sheikhi Didani and Dumlupinar (2022) also investigated the effects of progesterone (Pro), B-estradiol (ES), abscisic acid (ABA), and salicylic acid (SA) treatments on cold stress in bean seedlings. Antioxidant and nitrate assimilation enzyme activities, plant growth, chlorophyll, MDA, and hydrogen peroxide measurements were taken. According to the study results, plant growth decreased under cold stress, while MDA and H₂O₂ contents increased. Compared to the control, cold stress decreased nitrate reductase, nitrite reductase, and glutamate synthase enzyme activities, while they increased in Pro, ES, ABA, and SA treatments.

Kabay and Şensoy (2017) explored the effects of high temperature stress on tolerant and susceptible genotypes during five different growth stages. Biochemical, physiological, and elemental analyses were conducted in the study. Among the parameters examined, chlorophyll A, B, and A-B decreased compared to the control group in the treated and susceptible genotypes on the days examined. Except for MDA and APX enzymes, levels of CAT and SOD enzymes consistently increased across the treatment groups. While K and Ca levels in roots and shoots decreased, Na levels increased.

The effects of nitric oxide and trehalose treatment on managing heat stress in bean plants were explored. The results showed that nitric oxide and trehalose application improved the examined agronomic traits (Ahmed 2023). Da Silva et al. (2020) investigated the effects of high temperature stress on the reproductive biology of bean plants. Significant effects of high temperature stress were found on parameters such as 100-seed weight, seed yield, number of viable seeds, total pollen grains, number of flowers, pod set, and pods. Increasing temperature was found to decrease all parameters except the percentage of pod set, while it also caused increases in meiotic irregularities. Vargas et al. (2021) physiologically and genetically characterized the effects of heat stress on

the bean RIL population. Yields decreased under non-stress conditions. Furthermore, heat stress affected many traits throughout the reproductive phase under field conditions. In susceptible lines, the reproductive phase was prolonged, and defects that reduced seed filling, seed formation, and grain quality were detected. Higher yields under heat stress were associated with earlier flowering, effective seed filling, and high pollen viability.

3. BIOTIC STRESSES in COMMON BEAN

Biotic stress refers to the difficulties organisms experience due to their interactions with other living organisms, such as infections, pests, parasites, and competing organisms. It is known that biotic stress significantly affects crop yields and food security globally. Biotic stress causes a variety of physiological, biochemical, and molecular responses that significantly affect plant growth, development, and productivity. The mechanisms by which plants respond to biotic stress are complex. This complexity encompasses the host's resistance genes, the pathogen's virulence factors, and various environmental conditions.

Common bean is one of the most important legumes globally and a significant source of protein, carbohydrates, and nutrients (Hayat et al. 2014). However, numerous stress factors can affect bean growth and yield. Viruses, bacteria, and pests can cause severe yield losses. Biotic stress usually occurs in environments where disease management is poor and pathogens can proliferate. Plant-stress interactions in common bean have evolved over centuries, as in other plants. Understanding these complex dynamics, which result in infection developing in the pathogen and increased resistance and defense mechanisms in the plant, is very important for studies and breeding programs to develop resistance in common bean varieties.

3.1. Fungal Diseases

Fungal pathogens are widespread worldwide and major biotic stress factors affect production and yield. These pathogens can seriously affect the entire plant, from the shoot to the root, and from the seed to the stem. These organisms, which affect plants throughout the growth period, can also spread quickly and extensively, possibly affecting a large portion of the planting area in a short period.

Rust disease caused by *Uromyces appendiculatus* (Pers.:Pers.) Unger, an obligate biotrophic fungal pathogen, is one of the most damaging diseases affecting common beans. It causes significant worldwide losses in common bean production (Makhumbila et al. 2025). This pathogen has evolved alongside common beans, allowing it to overcome specific resistance genes easily. The leaves of infected plants are covered with distinct rust-colored pustules filled with urediniospores. This exposes the plant to biotic stress and initiates a different form of abiotic stress as the spreading disease inhibits light absorption by the plant's leaves. This reduces photosynthesis in the plant, causing it to weaken, become less productive, and in severe cases, die (Bassanezi et al. 2001; Yahya et al. 2020).

Another disease caused by *Colletotrichum lindemuthianum* is anthracnose. It represents the oldest and most extensively studied plant-pathogen system in plant pathology. This disease and pathogen have illuminated the molecular interactions between *P. vulgaris* and *C. lindemuthianum* (Nabi et al. 2022). The pathogen forms salmon-colored spore masses in the presence of moisture in the environment and causes collapsed lesions on the stem and leaves. Like rust disease, infected plants showed reduced photosynthetic activity (Bassanezi et al. 2001). There are a large number of identified isolates of this pathogen worldwide. This is another important consideration in the development of resistant varieties/cultivars.

The white mold disease is a plant disease that mainly strikes plants in humid and cool weather conditions. The fungus responsible for this infection is named *Sclerotinia sclerotiorum*. This necrotrophic pathogen produces sclerotia, named after itself, which makes disease management much more challenging. These sclerotia mycelia can persist in the soil for long planting/cropping seasons. Studies have shown that some common bean varieties exhibit physiological resistance to *S. sclerotiorum* (Robison et al. 2018). This pathogen generally produces enzymes that lyse the plant cell walls, causing foliage lesions and damage. It then proceeds to proliferate and grow in these necrotic lesions.

Fusarium, *Rhizoctonia*, *Pythium*, *Rhizoctonia*, *Pythium*, and *Phytophthora* are widespread, soil-borne root rot pathogens in beans. In most cases, these fungi can persist in dry soils for extended periods and usually infect plants in moist or wet soil conditions. In particular, *Pythium* species such as *P. debaryanum* and *P. ultimum* create significant difficulties in disease control because of their ability to remain in the soil for long periods, up to years (Schwartz et al. 2005). An interaction between waterlogging, an abiotic stress factor, and *Pythium* infection, a biotic stress, has been determined. Root rot pathogens often interact with other stressors and create complex scenarios to manage with a single approach (Li et al. 2014).

Due to investigations on seed-borne fungal pathogens in *P. vulgaris*, many pathogen species responsible for significant damage have been revealed (Marcenaro and Valkonen 2016; Dell’Olmo et al. 2023). Many seed-borne fungal species have been identified in bean-growing areas and fields. Among them are various genera such as *Colletotrichum*, *Macrophomina*, and *Alternaria*. These pathogens can also remain dormant in the seed for extended periods. Under optimal conditions, they become reactivated and infect the plants. This situation may lead to seed

rot, shoot failure, or infections that may not appear until later in the growth period. To prevent the transmission of fungal infections, it is essential to carry out seed-borne fungal pathogen diagnostics (Dell'Olmo et al. 2023).

3.2. Bacterial Diseases

Common Bacterial Blight (CBB) is the most significant bacterial disease affecting beans globally. *Xanthomonas citri* pv. *fuscans* (Xcf) and *Xanthomonas phaseoli* pv. *phaseoli* (Xpp) species are responsible for this disease. The disease is characterized by moisture-absorbing, browning of the leaves, often accompanied by a yellow halo, and usually results in mortality. Conditions that negatively affect plant growth also led to the development of the bacterium. As a result, all the leaves are subjected to blight. This disease can also spread in low doses throughout the entire plant, affecting pods and seeds, resulting in severe yield losses (Chen et al. 2021).

CBB can be transmitted through seeds. This brings a critical challenge for the global seed market. The bacteria remaining dormant in seeds for long periods can be the primary source of the following infection. Some Quantitative Trait Locus (QTL) studies have shown the existence of loci associated with CBB resistance in plants. However, many different factors are involved in the occurrence of this disease. This situation makes it challenging to develop resistant plant cultivars (Duncan et al. 2011). It is possible to manage CBB effectively. However, this requires multifaceted approaches such as pathogen-free seed, crop rotation, sterilization, and the development of resistant lines. Furthermore, to reduce the risk of disease, carefully selecting planting fields is also essential, as the bacteria can remain in the soil for long periods.

3.3. Viral Diseases

One of the essential biotic stress factors affecting *P. vulgaris* is viral infections. Viruses generally affect an organism's yield, and in plants, they significantly impact growth, development, and yield. The Bean common mosaic virus (BCMV) is a global viral threat to common beans. There are no pharmaceutical methods to combat viral infections. This makes genetic resistance the primary strategy for disease management (Expósito-Goás et al. 2024).

Symptoms of viral infections in common beans include mosaic patterns, damaged leaves, dwarfed growth, and low yields. Insects, machinery, or contaminated seeds can spread viral diseases. This transmission diversity makes it difficult to combat and control viral diseases. Combining conventional breeding and modern molecular biological techniques to develop virus/viral disease-resistant varieties is the most effective strategy for managing infections (Expósito-Goás et al. 2024).

3.4. Insecticide Diseases

Insects damage common beans in two main ways. The first is by feeding directly on the plant, and the second is indirectly transmitting plant pathogens during feeding or foraging. Sap-sucking whiteflies (*Bemisia tabaci*) are an important case study. Feeding by these insects reduces the vitality of plants, but more importantly, they cause greater damage by infecting plants with specific pathogens such as *Begomovirus* (eg, Bean golden mosaic virus). Regular insecticide applications are not preferred as they cause the development of resistance in insects and pose a risk of environmental pollution. Developing resistance to vectors or viruses through innovative strategies is one of the most important and powerful steps that can be taken in this regard (Ferreira et al. 2024). Pests that chew and feed on plant sap activate plant defense mechanisms

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(Jasmonic Acid/Salicylic Acid) and cause responses and changes in secondary metabolites.

Covering the field border with flowering plants increased the natural enemies of aphids, thereby protecting bean plants from insects without using insecticides. This experiment is a highly innovative and impressive approach to pest management on small farms (Ndakidemi et al. 2022). The common bean aphid (*Acanthoscelides obtectus*) is a major threat to stored grain. Laboratory studies have shown that spinetoram (an insecticide mixture derived from *Saccharopolyspora spinosa*) rapidly kills adult aphids on storage surfaces. However, since the efficacy of this pesticide varies depending on surface shape, surface structure, and exposure time, it is crucial to conduct real-world trials and develop innovative strategies (Sağlam et al. 2022).

It is essential to develop integrated approaches that use multiple methods to effectively manage biotic stress-induced diseases in common bean. Crop rotation, maintaining cleanliness, providing suitable field conditions, and using sterile seeds are important steps in disease management and prevention (Schwartz et al. 2005).

Using chemicals such as fungicides and antibacterials is an effective and quick method for protecting plants in the short term. However, this can lead to developing resistance in pathogens, so these applications must be carefully considered (Duncan et al. 2011). Preventive applications are more effective than therapeutic approaches. Developing disease-resistant varieties is the most effective approach to combating biotic stress in common bean. In addition, control strategies include beneficial approaches such as particular species of *Trichoderma* fungi and plant growth-promoting rhizobacteria. These organisms can inhibit pathogen growth through competitive and resistance-induced mechanisms. This could be a promising approach for reducing disease stress and improving plant health.

REFERENCES

- AbdElgawad, H., Zinta, G., Hamed, B. A., Selim, S., Beemster, G., Hozzein, W. N., Wadaan, M. A. M., Asard, H., & Abuelsoud, W. (2020). Maize roots and shoots show distinct oxidative stress and antioxidant defense profiles under heavy metal toxicity. *Environmental Pollution*, 258. <https://doi.org/10.1016/j.envpol.2019.113705>
- Ahmadian, K., Jalilian, J., & Pirzad, A. (2021). Nano-fertilizers improved drought tolerance in wheat under deficit irrigation. *Agricultural Water Management*, 244, 106544. <https://doi.org/10.1016/J.AGWAT.2020.106544>
- Ahmed, H. M. I. (2023). Heat Stress Management in Bean (*Phaseolus vulgaris* L.) through Nitric Oxide and Trehalose Interventions. *FARA Research Report*, 7(47), 594–603. <https://doi.org/10.59101/frr072347>
- Albuquerque, T. G., Bragotto, A. P. A., & Costa, H. S. (2022). Processed Food: Nutrition, Safety, and Public Health. *International Journal of Environmental Research and Public Health*, 19(24). <https://doi.org/10.3390/IJERPH192416410>
- Alcántara, E., Romera, F. J., Cañete, M., & De La Guardia, M. D. (1994). Effects of heavy metals on both induction and function of root Fe(III) reductase in Fe-deficient cucumber (*Cucumis sativus* L.) plants. *Journal of Experimental Botany*, 45(12), 1893–1898. <https://doi.org/10.1093/JXB/45.12.1893>
- Ali, B., Kumar, S., Sui, X., Niu, J., Yang, J., Zheng, M., Tang, Y., & Li, H. (2025). Exogenous acetylsalicylic acid mitigates cold stress in common bean seedlings by enhancing antioxidant defense and photosynthetic efficiency. *Frontiers in Plant Science*, 16, 1589706. <https://doi.org/10.3389/FPLS.2025.1589706>
- Ambachew, D., Mekbib, F., Asfaw, A., Beebe, S. E., & Blair, M. W. (2015). Trait associations in common bean genotypes grown under drought stress and field infestation by BSM bean fly. *The Crop Journal*, 3(4), 305–316. <https://doi.org/10.1016/J.CJ.2015.01.006>
- Ángel Martín-Rodríguez, J., Ariani, A., Leija, A., Elizondo, A., Fuentes, S. I., Ramirez, M., Gepts, P., Hernández, G., & Formey, D. (2021). *Phaseolus vulgaris* MIR1511 genotypic variations differentially regulate plant

- tolerance to aluminum toxicity. *Plant Journal*, 105(6), 1521–1533.
<https://doi.org/10.1111/TPJ.15129>
- Arif, N., Yadav, V., Singh, S., Kushwaha, B. K., Singh, S., Tripathi, D. K., Vishwakarma, K., Sharma, S., Dubey, N. K., & Chauhan, D. K. (2016). Assessment of Antioxidant Potential of Plants in Response to Heavy Metals. In A. Singh, S. M. Prasad, & R. P. Singh (Eds.), *Plant Responses to Xenobiotics*. Springer, pp. 97–125, Singapore.
https://doi.org/10.1007/978-981-10-2860-1_5
- Arenas-Huertero, C., Pérez, B., Rabanal, F., Blanco-Melo, D., De la Rosa, C., Estrada-Navarrete, G., Sanchez, F., Covarrubias, A. A., & Reyes, J. L. (2009). Conserved and novel miRNAs in the legume *Phaseolus vulgaris* in response to stress. *Plant Molecular Biology*, 70(4), 385–401.
<https://doi.org/10.1007/s11103-009-9480-3>
- Aroca, R., & Ruiz-Lozano, J. M. (2012). Regulation of Root Water Uptake Under Drought Stress Conditions. In R. Aroca (Ed.), *Plant Responses to Drought Stress: From Morphological to Molecular Features*. Springer, pp. 113–127, Berlin. https://doi.org/10.1007/978-3-642-32653-0_4
- Asfaw, A., Blair, M. W., Asfaw, A., & Blair, M. W. (2014). Quantification of drought tolerance in Ethiopian common bean varieties. *Agricultural Sciences*, 5(2), 124–139. <https://doi.org/10.4236/AS.2014.52016>
- Astaneh, N., Bazrafshan, F., Zare, M., Amiri, B., Bahrani, A., Astaneh, N., Bazrafshan, F., Zare, M., Amiri, B., & Bahrani, A. (2021). Nano-fertilizer prevents environmental pollution and improves physiological traits of wheat grown under drought stress conditions. *Scientia Agropecuaria*, 12(1), 41–47.
<https://doi.org/10.17268/SCI.AGROPECU.2021.005>
- Astudillo, C., Fernandez, A. C., Blair, M. W., & Cichy, K. A. (2013). The *Phaseolus vulgaris* ZIP gene family: Identification, characterization, mapping, and gene expression. *Frontiers in Plant Science*, 4(JUL), 50194. <https://doi.org/10.3389/FPLS.2013.00286>
- Bahadur, A., Batool, A., Nasir, F., Jiang, S., Mingsen, Q., Zhang, Q., Pan, J., Liu, Y., & Feng, H. (2019). Mechanistic Insights into Arbuscular Mycorrhizal Fungi-Mediated Drought Stress Tolerance in Plants.

- International Journal of Molecular Sciences, 20(17), 4199.
<https://doi.org/10.3390/ijms20174199>
- Bahmani, R., Modareszadeh, M., & Bihamta, M. R. (2020). Genotypic variation for cadmium tolerance in common bean (*Phaseolus vulgaris* L.). *Ecotoxicology and Environmental Safety*, 190, 110178.
<https://doi.org/10.1016/j.ecoenv.2020.110178>
- Basal, O., Szabó, A., & Veres, S. (2020). PEG-induced drought stress effects on soybean germination parameters. *Journal of Plant Nutrition*, 43(12), 1768–1779. <https://doi.org/10.1080/01904167.2020.1750638>
- Başdınç, T., & Çirka, M. (2021). Effects of urban sewage sludge on bean (*Phaseolus vulgaris* L.) seedling emergence rate and development. *Journal of Elementology*, 26(1), 181–197.
<https://doi.org/10.5601/JELEM.2020.25.4.2062>
- Bassanezi, R. B., Amorim, L., Bergamin Filho, A., Hau, B., & Berger, R. D. (2001). Accounting for photosynthetic efficiency of bean leaves with rust, angular leaf spot and anthracnose to assess crop damage. *Plant Pathology*, 50(4), 443–452. <https://doi.org/10.1046/J.1365-3059.2001.00584.X>
- Beatriz Gutiérrez-Martínez, P., Blanca, Ramírez-Hernández, C., Marcela, Maldonado-Villegas, M., & Maldonado-Villegas, M. M. (2024). Impact of cadmium on photosynthetic pigments, root structure, and nutrient concentrations in bean (*Phaseolus vulgaris* L.) plants. *Scientia Agropecuaria*, 15(4), 483–493.
<https://doi.org/10.17268/sci.agropecu.2024.035>
- Bian, Y., Chu, L., Lin, H., Qi, Y., Fang, Z., & Xu, D. (2022). PIFs- and COP1-HY5-mediated temperature signaling in higher plants. *Stress Biology*, 2(1), 35. <https://doi.org/10.1007/s44154-022-00059-w>
- Bothe, H. (2011). Plants in Heavy Metal Soils. In I. Sherameti & A. Varma (Eds.), *Detoxification of Heavy Metals*. Springer, pp. 35–57, Berlin.
https://doi.org/10.1007/978-3-642-21408-0_2
- Broughton, W. J., Hernández, G., Blair, M., Beebe, S., Gepts, P., & Vanderleyden, J. (2003). Beans (*Phaseolus* spp.) – model food legumes. *Plant and Soil*, 252(1), 55–128.
<https://doi.org/10.1023/A:1024146710611>

- Budak, H., Kantar, M., & Kurtoglu, K. Y. (2013). Drought tolerance in modern and wild wheat. *TheScientificWorldJournal*, 2013, 548246. <https://doi.org/10.1155/2013/548246>
- Cannata, M. G., Bertoli, A. C., Carvalho, R., Augusto, A. S., Bastos, A. R. R., Freitas, M. P., & Carvalho, J. G. (2015). Stress Induced by Heavy Metals Cd and Pb in Bean (*Phaseolus Vulgaris* L.) Grown in Nutrient Solution. *Journal of Plant Nutrition*, 38(4), 497–508. <https://doi.org/10.1080/01904167.2014.934476>
- Çelik, H., & Nadaroglu, H. (2018). An In vivo Investigation of the Effects of Some Heavy Metals on the Development of Beans (*Phaseolus vulgaris* L.). *International Journal of Innovative Research and Reviews*, 2(1), 7–10.
- Chatterjee, D., Patra, S., & Mandal, A. (2025). Small but Mighty: Role of miRNA in Abiotic Stress Responses and Crop Improvement. *Journal of Plant Growth Regulation*, 44(7), 3445–3462. <https://doi.org/10.1007/s00344-025-11627-5>
- Chen, N. W. G., Ruh, M., Darrasse, A., Foucher, J., Briand, M., Costa, J., Studholme, D. J., & Jacques, M. A. (2021). Common bacterial blight of bean: a model of seed transmission and pathological convergence. *Molecular Plant Pathology*, 22(12), 1464–1480. <https://doi.org/10.1111/MPP.13067>
- Chen, Y. E., Wu, N., Zhang, Z. W., Yuan, M., & Yuan, S. (2019). Perspective of monitoring heavy metals by moss visible chlorophyll fluorescence parameters. *Frontiers in Plant Science*, 10, 427198. <https://doi.org/10.3389/FPLS.2019.00035>
- Cheng, T., Xu, J., Ren, C., Wen, B., Zhang, W., Zhao, Q., Yu, G., & Zhang, Y. (2025). ABA as a downstream signal actively participates in phthalanilic acid mediated cold tolerance of common beans (*Phaseolus vulgaris*). *Plant Physiology and Biochemistry*, 220, 109594. <https://doi.org/10.1016/J.PLAPHY.2025.109594>
- Clapp, J. (2018). Mega-Mergers on the Menu: Corporate Concentration and the Politics of Sustainability in the Global Food System. *Global Environmental Politics*, 18(2), 12–33. https://doi.org/10.1162/glep_a_00454

- Da Silva, D. A., Pinto-Maglio, C. A. F., De Oliveira, É. C., De Moura Dos Reis, R. L., Carbonell, S. A. M., & Chiorato, A. F. (2020). Influence of high temperature on the reproductive biology of dry edible bean (*Phaseolus vulgaris* L.). *Scientia Agricola*, 77(3), e20180233. <https://doi.org/10.1590/1678-992X-2018-0233>
- Dadasoglu, E., Ekinci, M., Turan, M., & Yildirim, E. (2022). Ameliorative Effects of Biochar for Cadmium Stress on Bean (*Phaseolus vulgaris* L.) Growth. *Sustainability*, 14(23), 15563. <https://doi.org/10.3390/su142315563>
- Das, S., Modak, A., Rajkumar, M. S., Garhwal, V., Sethi, V., Jain, M., & Gangappa, S. N. (2025). The PHYTOCHROME INTERACTING FACTOR 3, a bHLH transcription factor, promotes thermosensory growth by directly activating PIF4 transcription and its protein accumulation in *Arabidopsis*. *New Phytologist*, 247(4), 1742–1762. <https://doi.org/10.1111/NPH.70278>
- Dell’Olmo, E., Zaccardelli, M., Basile, B., Corrado, G., & Sigillo, L. (2023). Identification and Characterization of New Seedborne Pathogens in *Phaseolus vulgaris* Landraces of Southern Italy. *Pathogens*, 12(1), 108. <https://doi.org/10.3390/PATHOGENS12010108>
- Dilek Tepe, H. (2022). Effect of gibberellic acid (GA3) addition on physiological parameters and metal uptake in *Phaseolus vulgaris* seedlings under cadmium and lead stress. *Plant Biosystems - An International Journal Dealing with All Aspects of Plant Biology*, 156(5), 1096–1106. <https://doi.org/10.1080/11263504.2021.2013331>
- Ding, Y., Shi, Y., & Yang, S. (2019). Advances and challenges in uncovering cold tolerance regulatory mechanisms in plants. *New Phytologist*, 222(4), 1690–1704. <https://doi.org/10.1111/NPH.15696>
- Ding, Y., & Yang, S. (2022). Surviving and thriving: How plants perceive and respond to temperature stress. *Developmental Cell*, 57(8), 947–958. <https://doi.org/10.1016/J.DEVCEL.2022.03.010>
- Dubey, A., Kumar, A., & Khan, M. L. (2020). Role of Biostimulants for Enhancing Abiotic Stress Tolerance in Fabaceae Plants. In M. Hasanuzzaman, S. Araújo, & S. S. Gill (Eds.), *The Plant Family Fabaceae: Biology and Physiological Responses to Environmental*

- Stresses*. Springer, pp. 223–236, Singapore. https://doi.org/10.1007/978-981-15-4752-2_8
- Duncan, R. W., Singh, S. P., & Gilbertson, R. L. (2011). Interaction of common bacterial blight bacteria with disease resistance quantitative trait loci in common bean. *Phytopathology*, 101(4), 425–435. <https://doi.org/10.1094/PHYTO-03-10-0095>
- Dutta, S., Islam, Z., Das, S., Barman, A., Chowdhury, M., Mondal, B. P., Ajnabi, J., & Manna, D. (2025). Harmonizing plant resilience: Unveiling the symphony of membrane lipid dynamics in response to abiotic stresses: a review. *Discover Plants*, 2(1), 61. <https://doi.org/10.1007/s44372-025-00152-0>
- Egamberdieva, D., Jabborova, D., & Wirth, S. (2013). Alleviation of Salt Stress in Legumes by Co-inoculation with *Pseudomonas* and *Rhizobium*. In N. K. Arora (Ed.), *Plant Microbe Symbiosis: Fundamentals and Advances*. Springer India, pp. 291–303, New Delhi. https://doi.org/10.1007/978-81-322-1287-4_11
- Ekinci, M., Yildirim, E., Açar, G., Arslan Yüksel, E., Aydin, M., Örs, S., & Kul, R. (2023). Determination of cadmium and/or drought stress effects on some plant phytohormone contents and hormone gene expressions in bean (*Phaseolus vulgaris* L). *Turkish Journal of Agriculture and Forestry*, 47(3), 402–411. <https://doi.org/10.55730/1300-011X.3096>
- El-Saadony, M. T., Desoky, E. S. M., Saad, A. M., Eid, R. S. M., Selem, E., & Elrys, A. S. (2021). Biological silicon nanoparticles improve *Phaseolus vulgaris* L. yield and minimize its contaminant contents on a heavy metals-contaminated saline soil. *Journal of Environmental Sciences*, 106, 1–14. <https://doi.org/10.1016/J.JES.2021.01.012>
- Emamverdian, A., Ding, Y., Mokhberdoran, F., & Ahmad, Z. (2020). Mechanisms of Selected Plant Hormones under Heavy Metal Stress. *Polish Journal of Environmental Studies*, 30(1), 497–507. <https://doi.org/10.15244/PJOES/122809>
- Expósito-Goás, S., Pinacho-Lieti, L. G., Lago-Pena, F., & Cabaleiro, C. (2024). Epidemiology and Management of Bean Common Mosaic Virus (BCMV) in Traditional *Phaseolus vulgaris* L. Landraces within Protected

- Geographical Indications. *Horticulturae*, 10(7), 699. <https://doi.org/10.3390/horticulturae10070699>
- Fadiji, A. E., Santoyo, G., Yadav, A. N., & Babalola, O. O. (2022). Efforts towards overcoming drought stress in crops: Revisiting the mechanisms employed by plant growth-promoting bacteria. *Frontiers in Microbiology*, 13, 962427. <https://doi.org/10.3389/FMICB.2022.962427>
- Faizan, M., Alam, P., Rajput, V. D., Faraz, A., Afzal, S., Ahmed, S. M., Yu, F.-Y., Minkina, T., & Hayat, S. (2023). Nanoparticle Mediated Plant Tolerance to Heavy Metal Stress: What We Know? *Sustainability*, 15(2), 1446. <https://doi.org/10.3390/su15021446>
- Fan, D., Hu, W., Xu, N., Seto, E. R., Lagarias, J. C., Chen, X., & Chen, M. (2025). A multisensor high-temperature signaling framework for triggering daytime thermomorphogenesis in *Arabidopsis*. *Nature Communications*, 16(1), 5197. <https://doi.org/10.1038/s41467-025-60498-7>
- Farid, M., Shakoor, M. B., Ehsan, S., Ali, S., Zubair, M., & Hanif, M. A. (2013). Morphological, physiological and biochemical responses of different plant species to Cd stress. *International Journal of Chemical and Biochemical Sciences*, 3, 53–60.
- Farooq, M., Nawaz, A., Chaudhary, M. A. M., & Rehman, A. (2017). Foliage-applied sodium nitroprusside and hydrogen peroxide improves resistance against terminal drought in bread wheat. *Journal of Agronomy and Crop Science*, 203(6), 473–482. <https://doi.org/10.1111/JAC.12215>
- Feng, Z., Ji, S., Ping, J., & Cui, D. (2021). Recent advances in metabolomics for studying heavy metal stress in plants. *TrAC Trends in Analytical Chemistry*, 143, 116402. <https://doi.org/10.1016/j.trac.2021.116402>
- Ferreira, A. L., Ghanim, M., Xu, Y., & Pinheiro, P. V. (2024). Interactions between Common Bean Viruses and Their Whitefly Vector. *Viruses*, 16(10), 1567. <https://doi.org/10.3390/v16101567>
- Franchi, L., Warner, N., Viani, K., & Nuñez, G. (2009). Function of Nod-like receptors in microbial recognition and host defense. *Immunological Reviews*, 227(1), 106–128. <https://doi.org/10.1111/J.1600-065X.2008.00734.X>

- Ge, Y., Li, Y., Zhu, Y. M., Bai, X., Lv, D. K., Guo, D., Ji, W., & Cai, H. (2010). Global transcriptome profiling of wild soybean (*Glycine soja*) roots under NaHCO₃ treatment. *BMC Plant Biology*, 10. <https://doi.org/10.1186/1471-2229-10-153>
- Gelaw, T. A., & Sanan-Mishra, N. (2021). Non-Coding RNAs in Response to Drought Stress. *International Journal of Molecular Sciences*, 22(22), 12519. <https://doi.org/10.3390/IJMS222212519>
- Ghanbari, A. A., Mousavi, S. H., Gorji, A. M., & Rao, İ. (2013). Effects of Water Stress on Leaves and Seeds of Bean (*Phaseolus vulgaris* L.). *Turkish Journal Of Field Crops*, 18(1), 73–77.
- Gobatto, D. R., Carneiro, E., Woyann, L. G., Abatti, L., & Finatto, T. (2025). Cold Stress During Common Bean (*Phaseolus vulgaris*) Reproductive Stage: Effects in Physiological and Agronomic Parameters. *Tropical Plant Biology*, 18(1), 38. <https://doi.org/10.1007/s12042-025-09407-2>
- Goodstein, D. M., Shu, S., Howson, R., Neupane, R., Hayes, R. D., Fazo, J., Mitros, T., Dirks, W., Hellsten, U., Putnam, N., & Rokhsar, D. S. (2012). Phytozome: A comparative platform for green plant genomics. *Nucleic Acids Research*, 40(D1). <https://doi.org/10.1093/NAR/GKR944>
- Hafez, E. M., Osman, H. S., El-Razek, U. A. A., Elbagory, M., Omara, A. E.-D., Eid, M. A., & Gowayed, S. M. (2021). Foliar-Applied Potassium Silicate Coupled with Plant Growth-Promoting Rhizobacteria Improves Growth, Physiology, Nutrient Uptake and Productivity of Faba Bean (*Vicia faba* L.) Irrigated with Saline Water in Salt-Affected Soil. *Plants*, 10(5), 894. <https://doi.org/10.3390/plants10050894>
- Hamid, N., Bukhari, N., & Jawaid, F. (2010). Physiological Responses of *Phaseolus Vulgaris* to Different Lead Concentrations. *Pakistan Journal of Botany*, 42(1), 239–246.
- Hammami, H., Parsa, M., Bayat, H., & Aminifard, M. H. (2022). The behavior of heavy metals in relation to their influence on the common bean (*Phaseolus vulgaris*) symbiosis. *Environmental and Experimental Botany*, 193, 104670. <https://doi.org/10.1016/J.ENVEXPBOT.2021.104670>
- Han, H. S., & Lee, K. D. (2005). Physiological responses of soybean-inoculation of *Bradyrhizobium japonicum* with PGPR in saline soil

- conditions. *Research Journal of Agriculture and Biological Sciences*, 1(3), 216–221.
- Hasan, M. K., Cheng, Y., Kanwar, M. K., Chu, X. Y., Ahammed, G. J., & Qi, Z. Y. (2017). Responses of plant proteins to heavy metal stress—a review. *Frontiers in Plant Science*, 8, 282807. <https://doi.org/10.3389/FPLS.2017.01492>
- Hasanuzzaman, M., Parvin, K., Bardhan, K., Nahar, K., Anee, T. I., Masud, A. A. C., & Fotopoulos, V. (2021). Biostimulants for the Regulation of Reactive Oxygen Species Metabolism in Plants under Abiotic Stress. *Cells*, 10(10), 2537. <https://doi.org/10.3390/cells10102537>
- Hashem, A., Kumar, A., Al-Dbass, A. M., Alqarawi, A. A., Al-Arjani, A. B. F., Singh, G., Farooq, M., & Abd_Allah, E. F. (2019). Arbuscular mycorrhizal fungi and biochar improves drought tolerance in chickpea. *Saudi Journal of Biological Sciences*, 26(3), 614–624. <https://doi.org/10.1016/J.SJBS.2018.11.005>
- Hashem, H. A., & El-Sherif, N. A. (2019). Exogenous Jasmonic Acid Induces Lead Stress Tolerance in Kidney Bean (*Phaseolus vulgaris* L.) by Changing Amino Acid Profile and Stimulating Antioxidant Defense System. *Jordan Journal of Biological Sciences*, 12(3), 345–353.
- Hayat, I., Ahmad, A., Masud, T., Ahmed, A., & Bashir, S. (2014). Nutritional and Health Perspectives of Beans (*Phaseolus vulgaris* L.): An Overview. *Critical Reviews in Food Science and Nutrition*, 54(5), 580–592. <https://doi.org/10.1080/10408398.2011.596639>
- He, S., Simpson, B. K., Sun, H., Ngadi, M. O., Ma, Y., & Huang, T. (2018). *Phaseolus vulgaris* lectins: A systematic review of characteristics and health implications. *Critical Reviews in Food Science and Nutrition*, 58(1), 70–83. <https://doi.org/10.1080/10408398.2015.1096234>
- Hediji, H., Kharbech, O., Massoud, M. Ben, Boukari, N., Debez, A., Chaibi, W., Chaoui, A., & Djebali, W. (2021). Salicylic acid mitigates cadmium toxicity in bean (*Phaseolus vulgaris* L.) seedlings by modulating cellular redox status. *Environmental and Experimental Botany*, 186, 104432. <https://doi.org/10.1016/J.ENVEXPBOT.2021.104432>
- Hidouri, S., Karmous, I., Kadri, O., Kharbech, O., & Chaoui, A. (2022). Clue of zinc oxide and copper oxide nanoparticles in the remediation of

- cadmium toxicity in *Phaseolus vulgaris* L. via the modulation of antioxidant and redox systems. *Environmental Science and Pollution Research*, 29(56), 85271–85285. <https://doi.org/10.1007/S11356-022-21799-2>
- Hwang, G., Lee, T., Park, J., Paik, I., Lee, N., Kim, Y. J., Song, Y. H., Kim, W. Y., & Oh, E. (2025). UV-B increases active phytochrome B to suppress thermomorphogenesis and enhance UV-B stress tolerance at high temperatures. *Plant Communications*, 6(1), 101142. <https://doi.org/10.1016/J.XPLC.2024.101142>
- Järup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin*, 68(1), 167–182. <https://doi.org/10.1093/BMB/LDG032>
- Jia, C., Guo, B., Wang, B., Li, X., Yang, T., Li, N., Wang, J., & Yu, Q. (2022). The LEA gene family in tomato and its wild relatives: Genome-wide identification, structural characterization, expression profiling, and role of SILEA6 in drought stress. *BMC Plant Biology*, 22(1), 596. <https://doi.org/10.1186/s12870-022-03953-7>
- Johnson, R., Joel, J. M., & Puthur, J. T. (2024). Biostimulants: The Futuristic Sustainable Approach for Alleviating Crop Productivity and Abiotic Stress Tolerance. *Journal of Plant Growth Regulation*, 43(3), 659–674. <https://doi.org/10.1007/S00344-023-11144-3>
- Kabay, T., & Şensoy, S. (2017). Yüksek Sıcaklığın Fasulyede Enzim, Klorofil ve İyon Değişimine Etkisi. *Ege Üniversitesi Ziraat Fakültesi Dergisi*, 54(4), 429–437.
- Kai, H. & Iba, K. (2014). Temperature Stress in Plants. In John Wiley & Sons, Ltd (Ed.), *Encyclopedia of Life Sciences*. John Wiley & Sons, Chichester. <https://doi.org/10.1002/9780470015902.a0001320.pub2>
- Kanwal, F., Riaz, A., Ali, S., & Zhang, G. (2024). NRAMPs and manganese: Magic keys to reduce cadmium toxicity and accumulation in plants. *Science of The Total Environment*, 921, 171005. <https://doi.org/10.1016/J.SCITOTENV.2024.171005>
- Khalil, R., Haroun, S., Bassyoini, F., Nagah, A., & Yusuf, M. (2021). Salicylic acid in combination with kinetin or calcium ameliorates heavy metal stress in *Phaseolus vulgaris* plant. *Journal of Agriculture and Food Research*, 5, 100182. <https://doi.org/10.1016/J.JAFR.2021.100182>

- Khatun, J., Intekhab, A., & Dhak, D. (2022). Effect of uncontrolled fertilization and heavy metal toxicity associated with arsenic(As), lead(Pb) and cadmium (Cd), and possible remediation. *Toxicology*, 477, 153274. <https://doi.org/10.1016/J.TOX.2022.153274>
- Kiran, Bharti, R., & Sharma, R. (2022). Effect of heavy metals: An overview. *Materials Today: Proceedings*, 51, 880–885. <https://doi.org/10.1016/J.MATPR.2021.06.278>
- Koleva, L., Umar, A., Yasin, N. A., Shah, A. A., Siddiqui, M. H., Alamri, S., Riaz, L., Raza, A., Javed, T., & Shabbir, Z. (2022). Iron Oxide and Silicon Nanoparticles Modulate Mineral Nutrient Homeostasis and Metabolism in Cadmium-Stressed *Phaseolus vulgaris*. *Frontiers in Plant Science*, 13, 806781. <https://doi.org/10.3389/FPLS.2022.806781>
- Kosakivska, I. V., Babenko, L. M., Romanenko, K. O., Korotka, I. Y., & Potters, G. (2021). Molecular mechanisms of plant adaptive responses to heavy metals stress. *Cell Biology International*, 45(2), 258–272. <https://doi.org/10.1002/CBIN.11503>
- Kothari, V. V., & Manuel, V. B. R. (2015). Effect of ACC-deaminase producing *Bacillus cereus* brm on the growth of *Vigna radiata* (Mung beans) under salinity stress. *Research Journal of Biotechnology*, 10(11), 122–130.
- Kul, R., Ekinici, M., & Yildirim, E. (2019). Effects of Lead Stress on Growth and Some Physiological Characteristics of Bean. *Global Journal of Botanical Science*, 7, 15–19. <https://doi.org/10.12974/2311-858X.2019.07.3>
- Kumawat, K. C., Sharma, P., Nagpal, S., Gupta, R. K., Sirari, A., Nair, R. M., Bindumadhava, H., & Singh, S. (2021). Dual Microbial Inoculation, a Game Changer? – Bacterial Biostimulants With Multifunctional Growth Promoting Traits to Mitigate Salinity Stress in Spring Mungbean. *Frontiers in Microbiology*, 11, 600576. <https://doi.org/10.3389/FMICB.2020.600576>
- Li, J., Li, H., Quan, X., Shan, Q., Wang, W., Yin, N., Wang, S., Wang, Z., & He, W. (2022a). Comprehensive analysis of cucumber C-repeat/dehydration-responsive element binding factor family genes and

- their potential roles in cold tolerance of cucumber. *BMC Plant Biology*, 22(1), 1–13. <https://doi.org/10.1186/S12870-022-03664-Z>
- Li, S., Han, X., Lu, Z., Qiu, W., Yu, M., Li, H., He, Z., & Zhuo, R. (2022b). MAPK Cascades and Transcriptional Factors: Regulation of Heavy Metal Tolerance in Plants. *International Journal of Molecular Sciences*, 23(8). <https://doi.org/10.3390/IJMS23084463>
- Li, Y. P., You, M. P., Colmer, T. D., & Barbetti, M. J. (2014). Effect of timing and duration of soil saturation on soilborne pythium diseases of common bean (*Phaseolus vulgaris*). *Plant Disease*, 99(1), 112–118. <https://doi.org/10.1094/PDIS-09-13-0964-RE>
- Liu, G., Li, B., Li, X., Wei, Y., He, C., & Shi, H. (2020). MaWRKY80 positively regulates plant drought stress resistance through modulation of abscisic acid and redox metabolism. *Plant Physiology and Biochemistry*, 156, 155–166. <https://doi.org/10.1016/J.PLAPHY.2020.09.015>
- Liu, Y., Hu, L., He, N., Jiang, Z., Gong, J., Jiang, C., & Zhao, H. (2025). Lead and cadmium adsorption by *Phanerochaete chrysosporium* under the protection of phosphorus-containing biochar: Effects and mechanisms. *Journal of Environmental Chemical Engineering*, 13(4), 117330. <https://doi.org/10.1016/J.JECE.2025.117330>
- Lizana, C., Wentworth, M., Martinez, J. P., Villegas, D., Meneses, R., Murchie, E. H., Pastenes, C., Lercari, B., Vernieri, P., Horton, P., & Pinto, M. (2006). Differential adaptation of two varieties of common bean to abiotic stress: I. Effects of drought on yield and photosynthesis. *Journal of Experimental Botany*, 57(3), 685–697. <https://doi.org/10.1093/JXB/ERJ062>
- López, C. M., Pineda, M., & Alamillo, J. M. (2020). Differential Regulation of Drought Responses in Two *Phaseolus vulgaris* Genotypes. *Plants*, 9(12), 1815. <https://doi.org/10.3390/plants9121815>
- Makhumbila, P., Rauwane, M., Muedi, H., & Figlan, S. (2025). Insights of *Phaseolus vulgaris*’ response to infection by *Uromyces appendiculatus* using an RNA-seq approach. *Frontiers in Plant Science*, 16, 1557954. <https://doi.org/10.3389/FPLS.2025.1557954>

- Malik, A., Yadav, P., & Singh, S. (2022). Role of polyamines in heavy metal stressed plants. *Plant Physiology Reports*, 27(4), 680–694. <https://doi.org/10.1007/s40502-022-00657-w>
- Małkowski, E., Sitko, K., Zieleźnik-Rusinowska, P., Gieroń, Ż., & Szopiński, M. (2019). Heavy Metal Toxicity: Physiological Implications of Metal Toxicity in Plants. In G. Sablok (Ed.), *Plant Metallomics and Functional Omics: A System-Wide Perspective*. Springer International Publishing, pp. 253–301, Cham. https://doi.org/10.1007/978-3-030-19103-0_10
- Manjeru, P., Madanzi, T., Makeredza, B., Nciizah, A., & Sithole, M. (2007). Effects of water stress at different growth stages on components and grain yield of common bean (*Phaseolus vulgaris* L.). *African Crop Science Conference Proceedings*, 8, 299–303.
- Marcenaro, D., & Valkonen, J. P. T. (2016). Seedborne Pathogenic Fungi in Common Bean (*Phaseolus vulgaris* cv. INTA Rojo) in Nicaragua. *PLOS ONE*, 11(12), e0168662. <https://doi.org/10.1371/JOURNAL.PONE.0168662>
- Márquez-Prieto, A. K., Palacio-Márquez, A., Sánchez, E., Macias-López, B. C., Pérez-Álvarez, S., Villalobos-Cano, O., & Preciado-Rangel, P. (2022). Impact of the foliar application of potassium nanofertilizer on biomass, yield, nitrogen assimilation and photosynthetic activity in green beans. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 50(1), 12569. <https://doi.org/10.15835/nbha50112569>
- Marthandan, V., Geetha, R., Kumutha, K., Renganathan, V. G., Karthikeyan, A., & Ramalingam, J. (2020). Seed Priming: A Feasible Strategy to Enhance Drought Tolerance in Crop Plants. *International Journal of Molecular Sciences*, 21(21), 8258. <https://doi.org/10.3390/ijms21218258>
- Mbarki, S., Skalicky, M., Vachova, P., Hajihashemi, S., Jouini, L., Zivcak, M., Tlustos, P., Brestic, M., Hejnak, V., & Zoghalmi Khelil, A. (2020). Comparing Salt Tolerance at Seedling and Germination Stages in Local Populations of *Medicago ciliaris* L. to *Medicago intertexta* L. and *Medicago scutellata* L. *Plants*, 9(4), 526. <https://doi.org/10.3390/plants9040526>

- Mladenov, P., Aziz, S., Topalova, E., Renaut, J., Planchon, S., Raina, A., & Tomlekova, N. (2023). Physiological Responses of Common Bean Genotypes to Drought Stress. *Agronomy*, 13(4), 1022. <https://doi.org/10.3390/AGRONOMY13041022>
- Mohammed, A., & Feleke, E. (2022). Future climate change impacts on common bean (*Phaseolus vulgaris* L.) phenology and yield with crop management options in Amhara Region, Ethiopia. *CABI Agriculture and Bioscience*, 3(1), 29. <https://doi.org/10.1186/s43170-022-00103-9>
- Monteiro, C.A., Cannon, G., Lawrence, M., Costa Louzada, M.L. & Pereira Machado, P. (2019). *Ultra-processed foods, diet quality, and health using the NOVA classification system*. FAO.
- Mosa, K. A., Ismail, A., & Helmy, M. (2017). Introduction to Plant Stresses. In K. A. Mosa, A. Ismail, & M. Helmy (Eds.), *Plant Stress Tolerance: An Integrated Omics Approach*. Springer International Publishing, pp. 1–19, Cham. https://doi.org/10.1007/978-3-319-59379-1_1
- Nabi, A., Lateef, I., Nisa, Q., Banoo, A., Rasool, R. S., Shah, M. D., Ahmad, M., & Padder, B. A. (2022). *Phaseolus vulgaris*-*Colletotrichum lindemuthianum* Pathosystem in the Post-Genomic Era: An Update. *Current Microbiology*, 79(2), 1–13. <https://doi.org/10.1007/S00284-021-02711-6>
- Ndakidemi, B. J., Mbega, E. R., Ndakidemi, P. A., Belmain, S. R., Arnold, S. E. J., Woolley, V. C., & Stevenson, P. C. (2022). Plant-Rich Field Margins Influence Natural Predators of Aphids More Than Intercropping in Common Bean. *Insects*, 13(7), 569. <https://doi.org/10.3390/INSECTS13070569>
- Noman, A., & Aqeel, M. (2017). miRNA-based heavy metal homeostasis and plant growth. *Environmental Science and Pollution Research*, 24(11), 10068–10082. <https://doi.org/10.1007/s11356-017-8593-5>
- Nongpiur, R., Soni, P., Karan, R., Singla-Pareek, S. L., & Pareek, A. (2012). Histidine kinases in plants: cross talk between hormone and stress responses. *Plant Signaling and Behavior*, 7(10), 1230–1237. <https://doi.org/10.4161/PSB.21516>
- Nowwar, A. I., Farghal, I. I., Ismail, M. A., & Amin, M. A. (2023). Impact of Irrigation with Wastewater on Accumulation of Heavy Metals in

- Phaseolus vulgaris* L. and Its Remediation. *Journal of Soil Science and Plant Nutrition*, 23(1), 761–777. <https://doi.org/10.1007/S42729-022-01080-8>
- Ponce, T. P., Bugança, M. da S., da Silva, V. S., de Souza, R. F., Moda-Cirino, V., & Tomaz, J. P. (2024). Differential Gene Expression in Contrasting Common Bean Cultivars for Drought Tolerance during an Extended Dry Period. *Genes*, 15(7). <https://doi.org/10.3390/GENES15070935>
- Pörtner, L. M., Von Philipsborn, P., & Fesenfeld, L. (2023). Food Security and Sustainability in Times of Multiple Crises. *Annals of Nutrition and Metabolism*, 79(1). <https://doi.org/10.1159/000527743>
- Postnikova, O. A., Shao, J., & Nemchinov, L. G. (2013). Analysis of the alfalfa root transcriptome in response to salinity stress. *Plant and Cell Physiology*, 54(7), 1041–1055. <https://doi.org/10.1093/PCP/PCT056>
- Pozo, M. J., López-Ráez, J. A., Azcón-Aguilar, C., & García-Garrido, J. M. (2015). Phytohormones as integrators of environmental signals in the regulation of mycorrhizal symbioses. *New Phytologist*, 205(4), 1431–1436. <https://doi.org/10.1111/NPH.13252>
- Qari, S. H., Hassan, M. U., Chattha, M. U., Mahmood, A., Naqve, M., Nawaz, M., Barbanti, L., Alahdal, M. A., & Aljabri, M. (2022). Melatonin Induced Cold Tolerance in Plants: Physiological and Molecular Responses. *Frontiers in Plant Science*, 13, 843071. <https://doi.org/10.3389/FPLS.2022.843071>
- Qing, D. J., Lu, H. F., Li, N., Dong, H. T., Dong, D. F., & Li, Y. Z. (2009). Comparative Profiles of Gene Expression in Leaves and Roots of Maize Seedlings under Conditions of Salt Stress and the Removal of Salt Stress. *Plant and Cell Physiology*, 50(4), 889–903. <https://doi.org/10.1093/PCP/PCP038>
- Rahut, D. B., Aryal, J. P., Manchanda, N., & Sonobe, T. (2022). Chapter 6 - Expectations for household food security in the coming decades: A global scenario. In R. Bhat (Ed.), *Future Foods*. Academic Press, pp. 107–131, Estonia. <https://doi.org/10.1016/B978-0-323-91001-9.00002-5>

- Rao, S., Balyan, S., Jha, S., & Mathur, S. (2020). Novel insights into expansion and functional diversification of MIR169 family in tomato. *Planta*, 251(2). <https://doi.org/10.1007/S00425-020-03346-W>
- Rawal, V., & Navarro, D. K. (Eds.). (2019). *The Global Economy of Pulses* (1st ed.). FAO, p. 190, Italy. <https://doi.org/10.4060/I7108EN>
- Raza, A., Hussain, S., Javed, R., Hafeez, M. B., & Hasanuzzaman, M. (2021). Antioxidant Defense Systems and Remediation of Metal Toxicity in Plants. In M. Hasanuzzaman (Ed.), *Approaches to the Remediation of Inorganic Pollutants*. Springer, pp. 91–124, Singapore. https://doi.org/10.1007/978-981-15-6221-1_6
- Recchia, G. H., Caldas, D. G. G., Beraldo, A. L. A., Da Silva, M. J., & Tsai, S. M. (2013). Transcriptional Analysis of Drought-Induced Genes in the Roots of a Tolerant Genotype of the Common Bean (*Phaseolus vulgaris* L.). *International Journal of Molecular Sciences*, 14(4), 7155–7179. <https://doi.org/10.3390/ijms14047155>
- Recchia, G. H., Konzen, E. R., Cassieri, F., Caldas, D. G. G., & Tsai, S. M. (2018). Arbuscular Mycorrhizal Symbiosis Leads to Differential Regulation of Drought-Responsive Genes in Tissue-Specific Root Cells of Common Bean. *Frontiers in Microbiology*, 9, 1339. <https://doi.org/10.3389/fmicb.2018.01339>
- Rehman, S., Chattha, M. U., Khan, I., Mahmood, A., Hassan, M. U., Al-Huqail, A. A., Salem, M. Z. M., Ali, H. M., Hano, C., & El-Esawi, M. A. (2022). Exogenously Applied Trehalose Augments Cadmium Stress Tolerance and Yield of Mung Bean (*Vigna radiata* L.) Grown in Soil and Hydroponic Systems through Reducing Cd Uptake and Enhancing Photosynthetic Efficiency and Antioxidant Defense Systems. *Plants*, 11(6), 822. <https://doi.org/10.3390/plants11060822>
- Robison, F. M., Turner, M. F., Jahn, C. E., Schwartz, H. F., Prenni, J. E., Brick, M. A., & Heuberger, A. L. (2018). Common bean varieties demonstrate differential physiological and metabolic responses to the pathogenic fungus *Sclerotinia sclerotiorum*. *Plant Cell and Environment*, 41(9), 2141–2154. <https://doi.org/10.1111/PCE.13176>
- Rodiño, A. P., & Drevon, J.-J. (2004). Migration of a Grain Legume, *Phaseolus vulgaris*, in Europe. In D. Werner (Ed.), *Biological Resources and*

- Migration*. Springer, pp. 61–71, Berlin, Heidelberg.
https://doi.org/10.1007/978-3-662-06083-4_6
- Sadeghipour, O., Babaei, H., & Pazaki, A. (2018). Study the effect of pre-treatment of seed with hydrogen peroxide on physiological and yield attributes traits of mung bean (*Vigna radiata* L.) under drought stress conditions. *Journal of Plant Ecophysiology*, 9(31), 23–31.
- Saini, S., Kaur, N., & Pati, P. K. (2021). Phytohormones: Key players in the modulation of heavy metal stress tolerance in plants. *Ecotoxicology and Environmental Safety*, 223, 112578.
<https://doi.org/10.1016/J.ECOENV.2021.112578>
- Sağlam, Ö., Çelik, A., Işıkber, A. A., Bozkurt, H., Sakka, M. K., & Athanassiou, C. G. (2022). Efficacy of Spinetoram for the Control of Bean Weevil, *Acanthoscelides obtectus* (Say.) (Coleoptera: Chrysomelidae) on Different Surfaces. *Insects*, 13(8), 723.
<https://doi.org/10.3390/insects13080723>
- Salama, D. M., Abd El-Aziz, M. E., Shaaban, E. A., Osman, S. A., & Abd El-Wahed, M. S. (2022). The impact of nanofertilizer on agromorphological criteria, yield, and genomic stability of common bean (*Phaseolus vulgaris* L.). *Scientific Reports*, 12(1), 18552.
<https://doi.org/10.1038/s41598-022-21834-9>
- Schmutz, J., Cannon, S. B., Schlueter, J., Ma, J., Mitros, T., Nelson, W., Hyten, D. L., Song, Q., Thelen, J. J., Cheng, J., Xu, D., Hellsten, U., May, G. D., Yu, Y., Sakurai, T., Umezawa, T., Bhattacharyya, M. K., Sandhu, D., Valliyodan, B., ... Jackson, S. A. (2010). Genome sequence of the palaeopolyploid soybean. *Nature*, 463(7278), 178–183.
<https://doi.org/10.1038/nature08670>
- Schwartz, H. F., Steadman, J. R., Hall, R., & Forster, R. L. (Eds.). (2005). *Compendium of bean diseases* (2nd ed.). American Phytopathological Society (APS Press), p. 190, USA.
- Shah, A. A., Riaz, L., Siddiqui, M. H., Nazar, R., Ahmed, S., Yasin, N. A., Ali, A., Mukherjee, S., Hussaan, M., Javad, S., & Chaudhry, O. (2022). Spermine-mediated polyamine metabolism enhances arsenic-stress tolerance in *Phaseolus vulgaris* by expression of zinc-finger proteins related genes and modulation of mineral nutrient homeostasis and

- antioxidative system. *Environmental Pollution*, 300, 118941. <https://doi.org/10.1016/j.envpol.2022.118941>
- Shaharoona, B., Arshad, M., & Zahir, Z. A. (2006). Effect of plant growth promoting rhizobacteria containing ACC-deaminase on maize (*Zea mays* L.) growth under axenic conditions and on nodulation in mung bean (*Vigna radiata* L.). *Letters in Applied Microbiology*, 42(2), 155–159. <https://doi.org/10.1111/J.1472-765X.2005.01827.X>
- Sharma, A., Kapoor, D., Gautam, S., Landi, M., Kandhol, N., Araniti, F., Ramakrishnan, M., Satish, L., Singh, V. P., Sharma, P., Bhardwaj, R., Tripathi, D. K., & Zheng, B. (2022). Heavy metal induced regulation of plant biology: Recent insights. *Physiologia Plantarum*, 174(3), e13688. <https://doi.org/10.1111/PPL.13688>
- Sheikhi Didani, B., & Dumlupinar, R. (2022). Common bean seedlings show increased tolerance to cool temperatures when treated with progesterone, β -oestradiol, abscisic acid, and salicylic acid. *Zemdirbyste-Agriculture*, 109(1), 43–48. <https://doi.org/10.13080/z-a.2022.109.006>
- Silva-Gigante, M., Hinojosa-Reyes, L., Rosas-Castor, J. M., Quero-Jiménez, P. C., Pino-Sandoval, D. A., & Guzmán-Mar, J. L. (2023). Heavy metals and metalloids accumulation in common beans (*Phaseolus vulgaris* L.): A review. *Chemosphere*, 335, 139010. <https://doi.org/10.1016/J.CHEMOSPHERE.2023.139010>
- Singh, A., Jha, S. K., Bagri, J., & Pandey, G. K. (2015). ABA Inducible Rice Protein Phosphatase 2C Confers ABA Insensitivity and Abiotic Stress Tolerance in *Arabidopsis*. *PLOS ONE*, 10(4), e0125168. <https://doi.org/10.1371/JOURNAL.PONE.0125168>
- Sofy, M. R., Aboseidah, A. A., Heneidak, S. A., & Ahmed, H. R. (2021). ACC deaminase containing endophytic bacteria ameliorate salt stress in *Pisum sativum* through reduced oxidative damage and induction of antioxidative defense systems. *Environmental Science and Pollution Research*, 28(30), 40971–40991. <https://doi.org/10.1007/S11356-021-13585-3>
- Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Boudirsky, B. L., Lassaletta, L., de Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R.,

- Scarborough, P., Rayner, M., Loken, B., Fanzo, J., ... Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature*, 562(7728), 519–525. <https://doi.org/10.1038/s41586-018-0594-0>
- Srivastava, V., Soni, A., & Sonam, K. (2015). Analysis on Effect of Cold Stress in Bean Seeds (*Phaseolus vulgaris* L). *American Journal of BioScience*, 3(4), 145–166. <https://doi.org/10.11648/J.AJBIO.20150304.15>
- Stoeva, N., Berova, M., & Zlatev, Z. (2005). Effect of arsenic on some physiological parameters in bean plants. *Biologia Plantarum*, 49(2), 293–296. <https://doi.org/10.1007/S10535-005-3296-Z>
- Su, X., Yao, L., Wang, X., Zhang, Y., Zhang, G., & Li, X. (2025). Mechanisms for cell survival during abiotic stress: focusing on plasma membrane. *Stress Biology*, 5(1), 1. <https://doi.org/10.1007/S44154-024-00195-5>
- Su, Y. H., McGrath, S. P., & Zhao, F. J. (2010). Rice is more efficient in arsenite uptake and translocation than wheat and barley. *Plant and Soil*, 328(1), 27–34. <https://doi.org/10.1007/S11104-009-0074-2>
- Swinburn, B. A., Sacks, G., Hall, K. D., McPherson, K., Finegood, D. T., Moodie, M. L., & Gortmaker, S. L. (2011). The global obesity pandemic: Shaped by global drivers and local environments. *The Lancet*, 378(9793), 804–814. [https://doi.org/10.1016/S0140-6736\(11\)60813-1](https://doi.org/10.1016/S0140-6736(11)60813-1)
- Temba, M. C., Njobeh, P. B., Adebo, O. A., Olugbile, A. O., & Kayitesi, E. (2016). The role of compositing cereals with legumes to alleviate protein energy malnutrition in Africa. *International Journal of Food Science and Technology*, 51(3), 543–554. <https://doi.org/10.1111/IJFS.13035>
- Thanmalagan, R. R., Jayaprakash, A., Roy, A., Arunachalam, A., & Lakshmi, P. T. V. (2022). A review on applications of plant network biology to understand the drought stress response in economically important cereal crops. *Plant Gene*, 29, 100345. <https://doi.org/10.1016/J.PLGENE.2021.100345>
- Uebersax, M. A., Cichy, K. A., Gomez, F. E., Porch, T. G., Heitholt, J., Osorno, J. M., Kamfwa, K., Snapp, S. S., & Bales, S. (2023). Dry beans (*Phaseolus vulgaris* L.) as a vital component of sustainable agriculture and food security—A review. *Legume Science*, 5(1), e155. <https://doi.org/10.1002/LEG3.155>

- Urwat, U., Ahmad, S. M., Masi, A., Ganai, N. A., Murtaza, I., Khan, I., & Zargar, S. M. (2021). Fe and Zn stress induced gene expression analysis unraveled mechanisms of mineral homeostasis in common bean (*Phaseolus vulgaris* L.). *Scientific Reports*, 11(1), 1–17. <https://doi.org/10.1038/S41598-021-03506-2>
- Vargas, Y., Mayor-Duran, V. M., Buendia, H. F., Ruiz-Guzman, H., & Raatz, B. (2021). Physiological and genetic characterization of heat stress effects in a common bean RIL population. *PLOS ONE*, 16(4), e0249859. <https://doi.org/10.1371/JOURNAL.PONE.0249859>
- Varshney, R. K., Song, C., Saxena, R. K., Azam, S., Yu, S., Sharpe, A. G., Cannon, S., Baek, J., Rosen, B. D., Tar'an, B., Millan, T., Zhang, X., Ramsay, L. D., Iwata, A., Wang, Y., Nelson, W., Farmer, A. D., Gaur, P. M., Soderlund, C., ... Cook, D. R. (2013). Draft genome sequence of chickpea (*Cicer arietinum*) provides a resource for trait improvement. *Nature Biotechnology*, 31(3), 240–246. <https://doi.org/10.1038/nbt.2491>
- Verbruggen, N., Hermans, C., & Schat, H. (2009). Molecular mechanisms of metal hyperaccumulation in plants. *New Phytologist*, 181(4), 759–776. <https://doi.org/10.1111/J.1469-8137.2008.02748.X>
- von Grebmer, K., Saltzman, A., Birol, E., Wiesmann, D., Prasai, N., Yin, S., Yohannes, Y., Menon, P., Thompson, J., & Sonntag, A. (2014). *2014 Global hunger index: The challenge of hidden hunger*. Welthungerhilfe, International Food Policy Research Institute and Concern Worldwide, p.51, Germany. <https://doi.org/10.2499/9780896299580>
- Wang, H., Lu, S., Guan, X., Jiang, Y., Wang, B., Hua, J., & Zou, B. (2022). Dehydration-Responsive Element Binding Protein 1C, 1E, and 1G Promote Stress Tolerance to Chilling, Heat, Drought, and Salt in Rice. *Frontiers in Plant Science*, 13, 851731. <https://doi.org/10.3389/FPLS.2022.851731>
- Westhoek, H., Lesschen, J. P., Rood, T., Wagner, S., De Marco, A., Murphy-Bokern, D., Leip, A., van Grinsven, H., Sutton, M. A., & Oenema, O. (2014). Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. *Global Environmental Change*, 26(1), 196–205. <https://doi.org/10.1016/J.GLOENVCHA.2014.02.004>

- Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., Vries, W. D., Sibanda, L. M., ... Murray, C. J. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, 393(10170), 447–492. [https://doi.org/10.1016/S0140-6736\(18\)31788-4](https://doi.org/10.1016/S0140-6736(18)31788-4)
- Wu, J., Chen, J., Wang, L., & Wang, S. (2017). Genome-Wide Investigation of WRKY Transcription Factors Involved in Terminal Drought Stress Response in Common Bean. *Frontiers in Plant Science*, 8. <https://doi.org/10.3389/fpls.2017.00380>
- Wu, J., Wang, L., & Wang, S. (2016). Comprehensive analysis and discovery of drought-related NAC transcription factors in common bean. *BMC Plant Biology*, 16(1), 193. <https://doi.org/10.1186/s12870-016-0882-5>
- Wu, L., Chang, Y., Wang, L., Wang, S., & Wu, J. (2022). The aquaporin gene PvXIP1;2 conferring drought resistance identified by GWAS at seedling stage in common bean. *Theoretical and Applied Genetics*, 135(2), 485–500. <https://doi.org/10.1007/s00122-021-03978-w>
- Xu, P., Liu, Z., Fan, X., Gao, J., Zhang, X., Zhang, X., & Shen, X. (2013). De novo transcriptome sequencing and comparative analysis of differentially expressed genes in *Gossypium aridum* under salt stress. *Gene*, 525(1), 26–34. <https://doi.org/10.1016/J.GENE.2013.04.066>
- Xu, T., Patitaki, E., Zioutopoulou, A., & Kaiserli, E. (2025). Light and high temperatures control epigenomic and epitranscriptomic events in *Arabidopsis*. *Current Opinion in Plant Biology*, 83, 102668. <https://doi.org/10.1016/J.PBI.2024.102668>
- Yahya, M., Saeed, N. A., Nadeem, S., Hamed, M., & Saleem, K. (2020). Effect of leaf rust disease on photosynthetic rate, chlorophyll contents and grain yield of wheat. *Archives of Phytopathology and Plant Protection*, 53(9–10), 425–439. <https://doi.org/10.1080/03235408.2020.1748369>
- Yang, X., Liu, C., Li, M., Li, Y., Yan, Z., Feng, G., & Liu, D. (2023). Integrated transcriptomics and metabolomics analysis reveals key regulatory network that response to cold stress in common Bean (*Phaseolus vulgaris*)

- L.). *BMC Plant Biology*, 23(1), 85. <https://doi.org/10.1186/s12870-023-04094-1>
- Yildirim, E., Agar, G., Ors, S., Yuksel, E. A., Aydin, M., Ekinci, M., & Kul, R. (2023). Growth, physiological, biochemical and DNA methylation responses to cadmium stress of bean (*phaseolus vulgaris* L) grown under different irrigation levels. *Plant Growth Regulation*, 101(2), 537–556. <https://doi.org/10.1007/s10725-023-01039-4>
- You, J., & Chan, Z. (2015). Ros regulation during abiotic stress responses in crop plants. *Frontiers in Plant Science*, 6(DEC), 165102. <https://doi.org/10.3389/FPLS.2015.01092/XML>
- Young, N. D., Debellé, F., Oldroyd, G. E. D., Geurts, R., Cannon, S. B., Udvardi, M. K., Benedito, V. A., Mayer, K. F. X., Gouzy, J., Schoof, H., Van de Peer, Y., Proost, S., Cook, D. R., Meyers, B. C., Spannagl, M., Cheung, F., De Mita, S., Krishnakumar, V., Gundlach, H., ... Roe, B. A. (2011). The Medicago genome provides insight into the evolution of rhizobial symbioses. *Nature*, 480(7378), 520–524. <https://doi.org/10.1038/nature10625>
- Younis, M. E., Tourky, S. M. N., & Elsharkawy, S. E. A. (2018a). Element content, growth and metabolic changes in Cu- and Cd- stressed *Phaseolus vulgaris* plants. *Journal of Plant and Environmental Research*, 3, 9. <https://doi.org/10.28933/JPER-2018-07-2001>
- Younis, M. E., Tourky, S. M. N., & Elsharkawy, S. E. A. (2018b). Symptomatic parameters of oxidative stress and antioxidant defense system in *Phaseolus vulgaris* L. in response to copper or cadmium stress. *South African Journal of Botany*, 117, 207–214. <https://doi.org/10.1016/J.SAJB.2018.05.019>
- Zhang, H., Zhao, Y., & Zhu, J. K. (2020). Thriving under Stress: How Plants Balance Growth and the Stress Response. *Developmental Cell*, 55(5), 529–543. <https://doi.org/10.1016/J.DEVCEL.2020.10.012>
- Zhang, Q., Geng, J., Du, Y., Zhao, Q., Zhang, W., Fang, Q., Yin, Z., Li, J., Yuan, X., Fan, Y., Cheng, X., & Du, J. (2022). Heat shock transcription factor (Hsf) gene family in common bean (*Phaseolus vulgaris*): Genome-wide identification, phylogeny, evolutionary expansion and expression

- analyses at the sprout stage under abiotic stress. *BMC Plant Biology*, 22(1), 33. <https://doi.org/10.1186/s12870-021-03417-4>
- Zhang, R., Yang, L., Zhang, H., Yang, Y., Wen, L., Yin, A., & Fu, L. (2025). Molecular Networks Governing Plant Responses to Heat and Cold Stress. *Plants*, 14(13), 2073. <https://doi.org/10.3390/plants14132073>
- Zhou, L., Liu, Z., Liu, Y., Kong, D., Li, T., Yu, S., Mei, H., Xu, X., Liu, H., Chen, L., & Luo, L. (2016). A novel gene OsAHL1 improves both drought avoidance and drought tolerance in rice. *Scientific Reports*, 6. <https://doi.org/10.1038/SREP30264>
- Zhou, P., Adeel, M., Shakoor, N., Guo, M., Hao, Y., Azeem, I., Li, M., Liu, M., & Rui, Y. (2020a). Application of Nanoparticles Alleviates Heavy Metals Stress and Promotes Plant Growth: An Overview. *Nanomaterials*, 11(1), 26. <https://doi.org/10.3390/NANO11010026>
- Zhou, R., Yu, X., Ottosen, C.-O., Zhang, T., Wu, Z., & Zhao, T. (2020b). Unique miRNAs and their targets in tomato leaf responding to combined drought and heat stress. *BMC Plant Biology*, 20(1), 107. <https://doi.org/10.1186/s12870-020-2313-x>
- Zhu, J. K. (2016). Abiotic Stress Signaling and Responses in Plants. *Cell*, 167(2), 313–324. <https://doi.org/10.1016/J.CELL.2016.08.029>
- Zupin, M., Sedlar, A., Kidrič, M., & Meglič, V. (2017). Drought-induced expression of aquaporin genes in leaves of two common bean cultivars differing in tolerance to drought stress. *Journal of Plant Research*, 130(4), 735–745. <https://doi.org/10.1007/S10265-017-0920-X>