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Amelioration of Abiotic Stress and Climate Change Resilience in Chickpea

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ABSTRACT

Chickpea, an important legume crop high in protein mostly grown under rainfed circumstances in arid and semi-arid climates, where it is extremely subject to abiotic stresses like drought, terminal stress, temperature, water logging at different growth stages throughout the season linked to severe yield losses, particularly when the crop is subjected to unfavorable conditions during the reproductive period, leading to instability in chickpea production around the world. This review aims to provide a comprehensive overview of the strategies employed for ameliorating abiotic stress and enhancing climate change resilience in chickpea. It examines the physiological, biochemical, and molecular responses of chickpea plants to abiotic stress and explores the underlying mechanisms involved in stress tolerance. The review highlights the importance of understanding the genetic basis of stress tolerance traits and emphasizes the potential for genetic improvement through breeding and genetic engineering approaches. It examines the physiological, biochemical, and molecular responses of chickpea plants to abiotic stress and explores the underlying mechanisms involved in stress tolerance. It discusses the identification of stress-responsive genes, proteins, and metabolites, which can serve as potential targets for crop improvement and the development of stress-tolerant chickpea varieties. In conclusion, this comprehensive review provides valuable insights into the amelioration of abiotic stress and climate change resilience in chickpea. It synthesizes current knowledge, identifies research gaps, and offers practical recommendations for sustainable chickpea production under challenging environmental conditions.

Keywords Abiotic stress, Climatic resistances, Chickpea, PGPR biotechnology tools for abiotic stress elevation.

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INTRODUCTION

After dry beans, chickpeas (*Cicer arietinum* L.) are the second-most significant legume crop worldwide (Varshney *et al*. 2013). For persons who cannot afford animal protein or who are mostly vegetarians, chickpeas provide an affordable and significant source of protein. In addition, chickpeas are an excellent source of fiber, unsaturated fatty acids, and minerals including calcium, phosphorus, magnesium, zinc, and iron. Chickpeas also contribute significantly to soil fertility maintenance by fixing nitrogen at rates of up to 140 kg/ha/year (Flowers *et al*. 2010). Because it receives 70% of its nitrogen via symbiotic N_2 fixation and helps other cereal crops, this crop only needs comparatively little nitrogen inputs. The addition of organic matter and a sizable quantity of residual nitrogen from chickpeas improves the health and fertility of the soil. The production of chickpeas is hampered by a variety of abiotic stressors, including drought and extremes of temperature (Jha *et al.* 2014).

Abiotic constraints to chickpea production

Abiotic stressors including salt, drought, and extreme heat have an impact on crop development and yield. Seasonal changes brought on by this rise in temperature have a considerable impact on chickpea output. Plants that have been exposed to cold stress exhibit phenotypic consequences such as poor germination, stunted seedlings, yellowing of the leaves (chlorosis), decreased leaf growth and wilting, and tissue death (necrosis). Cold stress effects during the reproductive stage also include flower abortion and a reduction in pollen tube development (Kiran *et al.* 2019). The greatest harm caused by cold stress on plants, however, is severe membrane damage brought on by cellular dehydration brought on by freezing during cold stress. Due to inappropriate irrigation and agricultural land management techniques that result in high concentrations of harmful ions (Na^+ and Cl) on arable land, soil salinity stress is one of the rising challenges in the globe (Ismail and Hopie 2017). The overabundance of soluble salts in the soils causes ionic imbalance, osmotic stress, and ion toxicity, which can kill plants (Rasool *et al.* 2015). Salinity in the soil has a considerable negative impact on chickpea yields. Damage to photosystem II and nutritional imbalance, which reduces germination, plant development (biomass) and seed size are some of the consequences of salt on biological processes (Fig. 1) (Khan *et al.* 2015).

Impact of drought in chickpea

A fair tolerance to abiotic pressures requires the expression of several genes since abiotic stress is a complicated feature that may include numerous genes. For the purpose of enhancing chickpeas, the development of genetically modified (GM) plants by the introduction and/or over expression of certain gene (s) appears to be extremely promising. Water channel proteins, essential enzymes for osmolyte production (proline, betaine, sugars like trehalose, and polyamines), detoxifying enzymes, and transport proteins are only a few examples of known stress-induced genes that have been utilized for genetic transformation. It will also be easier to increase crop's water usage efficiency

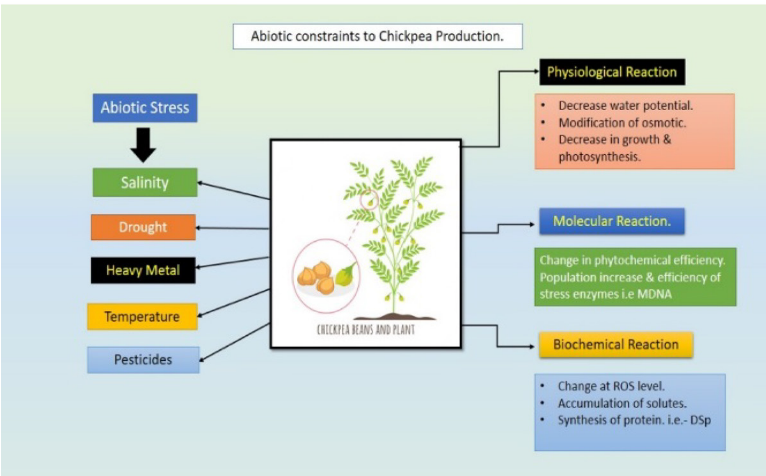

Fig. 1. Abiotic constraints of chickpea production.

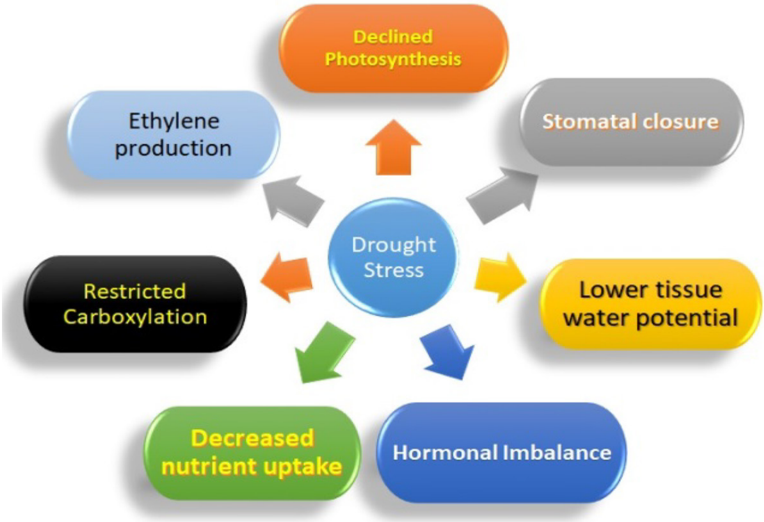

Fig. 2. Impact of drought on crop productivity.

and drought tolerance by knowing the physiological mechanisms that control drought tolerance and the related regulatory genes. Additionally, research on the chickpea's functional genomics will aid in the advancement of the legume. In the reproductive stage, the chickpea experiences "terminal drought", which can seriously hamper reproductive functions such as anthesis and pollination as well as pollen germination, pollen viability, fertility, and pollen tube growth as well as stigma and style dysfunction (Pang *et al.* 2017) (Fig. 2). Water shortage during chickpea podding increased Abscisic acid (ABA), which might affect pod set and result in pod abscission, which could eventually result in severe output losses (Pang *et al.* 2017).

Temperature effect in chickpea

High temperature stress

Chickpea growth and development can be negatively impacted by temperatures exceeding 35°C (heat stress), particularly during the reproductive phase, which can result in large yield losses (Devasirvatham *et al.* 2015). Early mature genotypes are able to escape late season heat stress, but those with late maturation are exposed throughout the blooming and podding phases and may experience yield penalties. Days till blooming are inversely correlated with yield, with pod quantity per plant and harvesting index (HI) being the factors most significantly associated with grain yield under heat stress (Devasirvatham *et al.* 2015). The physiological and biochemical processes are impacted by heat stress during the seed filling stage, which has an influence on seed development. The carbon-fixing enzyme Rubisco, the sucrose-cleaving enzyme, Invertase, the sucrose-synthesising enzymes, Sucrose phosphate synthase (SPS) and Sucrose synthase (SS) and their enzymatic activities all decrease as a result at the biochemical level (Kaushal *et al.* 2013). This has the effect of lowering the sucrose content of the leaves and anthers.

Low temperature stress

Low temperatures may be further broken down into two ranges: The freezing/frost range, which is below 1.5°C and the chilling range which is between 1.5 and 15°C. Both ranges have an impact on chickpea development and output. By exposing oneself to low temperatures beforehand, or "cold acclimation," one might develop a tolerance to low temperatures. Frost damage inhibits pollen viability, stigma receptivity, *in vivo* pollen germination and pollen tube elongation which eventually results in unsuccessful ovule fertilization and decreased seed output (Berger *et al.* 2012). Kabuli kinds tend to be more vulnerable to low temperature damage than desi types because they have a testa that is thinner and allows for quicker water absorption and more imbibitional damage (Rani *et al.* 2020).

Salinity

Another abiotic factor that may restrict crop yield is salinity in the water or soil, particularly in dry or semi-arid areas. Salinity has a negative impact on plants due to a variety of variables, including nutrient imbalance, particular ion impacts, low osmotic potential of the soil, and nutritional deficiencies (Isayenkov and Maathuis 2019). Salinity typically has both short-term effects (such as ion-independent growth reduction) that occur minutes to hours or days after perception of the stimuli, closed stomata and shoot-specific inhibition of cell expansion and long-term effects (such as building up cytotoxic ion levels, slowing the metabolic activities and causing early senescence and ultimately cell death) that can occur over days or even weeks (Roy *et al.* 2014), one of them is osmotic tolerance, which uses speedy communication pathways between roots and shoots to respond quickly and quickly lower stomatal conductance to store water (Maischak *et al.* 2010). The activation of numerous signalling cascades that limit net Na^+ inflow and minimise net Na^+ translocation is how the ionic tolerance is accomplished (Isayenkov and Maathuis 2019).

Heavy metals

Heavy metals (HMs) like Mn, Cu, Ni, Co, Cd, Fe, Zn and Hg among others have accumulated in soils as a result of a number of anthropogenic activities including the application of fertilizer, the improper disposal of industrial wastes, the unrestrained sewage disposals or the improper disposal of automobile effluents. They are either collected on the soil surface or are leached from the soil into the groundwater. It also negatively affects enzymes by inactivating or denaturing them. According to reports, HMs disrupt the substitution reaction of necessary metallic ions with biomolecules, which compromises the integrity of membranes and alters respiration, photosynthetic capacity, and other processes (Hossain *et al*. 2012). By promoting the generation of hydroxyl radicals (OH), superoxide radicals (O_2), and hydrogen peroxide (H_2O_2), HMs also cause oxidative stress (Rascio and Navari-Izzo 2011). Glutathione, phytochelatins, metallothioneins, amino acids and specific enzymes like superoxide dismutase (SOD) are some of the substances that are involved in this process (Hossain *et al.* 2012). A plant may also cope with HMs by altering the pH of the rhizosphere which causes HMs to precipitate, transferring metallic ions from symplastic to aplastic space utilizing metal transport and carrier proteins, and secreting exudates from the roots such malate and oxalate.

Biotechnological techniques and breeding strategies for sustainable agro ecological system and abiotic stress amelioration

A biological reaction is produced as a result of the signals that are recognised following environmental stimulation. Genes and transcription factors, which are also activated in response to these stimuli, play a major role in mediating these reactions. Additionally, these environmental factors cause the synthesis of redox molecules like ROS and RNS (reactive nitrogen species) (Cramer *et al.* 2011), which activate downstream signalling cascades involving the activation of genes that code for products (proteins, metabolites) that may aid the plant in avoiding or resisting stress conditions (Fig. 3). Moreover, environmental stress reacts similarly to other types of stress. For instance, many genes that are activated by dryness also respond similarly to salt and cold and genes that are activated during drought stress protect cells from water deficiency circumstances as well as activate genes that lead to the creation of essential metabolic proteins that control signal transduction during drought stress (Takahashi *et al.* 2020).

CRISPR technology in abiotic stress tolerance

Abiotic stress responses are very variable and dynamic, and they are frequently regulated by several genes spread across extensive quantitative trait loci (QTLs). The use of plasmids or cosmids with a restricted ability to transport and ectopically express foreign genes in plants is a common practise in traditional genetic engineering. When foreign genes are introduced into plants to change certain qualities, these changes frequently interfere with other traits and result in un-

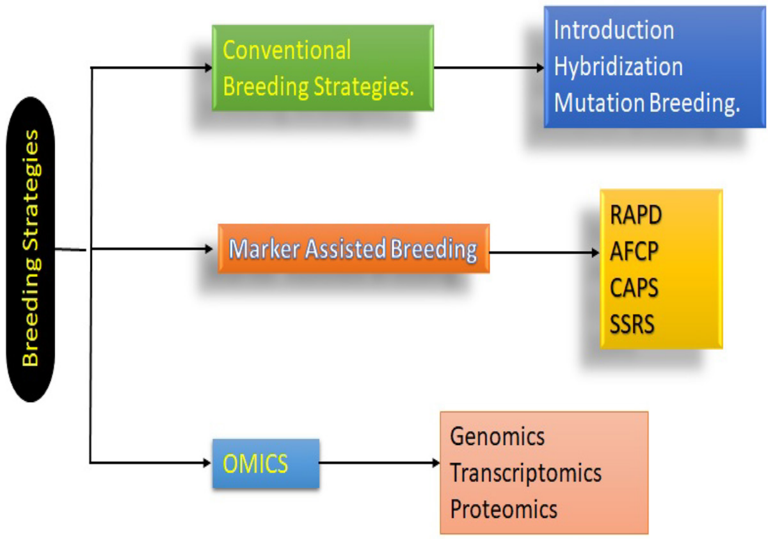

Fig. 3. Breeding strategies and biotechnological tools.

desired phenotypes. In many nations, it is technically forbidden to release or consume genetically modified organisms (GMOs), and their use is subject to tight regulations. The original base pair arrangement of an organism's genome must be changed when CRISPR/Cas9 is used for genome editing. Hence, since no foreign genetic material is introduced, the plants produced using this approach are not often regarded as GMOs. A key benefit of the CRISPR/Cas9 technology is the ability to simultaneously edit several target genes (De Souza *et al.* 2020). Among these are genes related to photorespiration, proline accumulation, ion transport, compartmentalization, phytohormone control, ion acquisition in the roots, Na^+/K^+ acquisition, homeostasis, and other processes (Farhat *et al.* 2019).

PGPR – A sustainable green alternative to climate change resilience and abiotic stress amelioration

Researchers are exploring several strategies that might sustainably boost agricultural yield, such as the use of *Phyto microbiome* components, which is increasingly acknowledged as a "fresh" green revolution. Although beneficial microorganisms' use on food crops has been extensively investigated, there are very few examples of them actually being used in the field. The negative impacts associated with the excessive application of chemical inputs (fertilizers and pesticides) might be mitigated by including *Phyto microbiome* members in agricultural systems as a sustainable approach to disease management and nutritional supplementation (Antar *et al.* 2021) (Fig. 4).

PGPR mediated nitrogen fixation for plant growth amelioration

Nitrogen is one of the most crucial mineral nutrients for plants since it is necessary for many physiological activities, such as protein synthesis and photosynthesis, in plants (Alori *et al.* 2017). According to Bouchet *et al.* (2016), cropping systems are only able to collect around 50% of the additional nitrogen; the remaining 50% either remains in the soil as organic complexes (which account for about 98% of the total nitrogen in the soil) or escapes through volatilization, leaching, and runoff. On the basis of the sort of relationship they have evolved with plants, nitrogen fixers may be divided into two main categories: Symbionts and free-living nitrogen fixers. *Rhizobium, Sinorhizobium, Azoarcus, Mesorhizobium, Frankia, Allorhizobium, Bradyrhizobium, Burkholderia, Azorhizobium* and

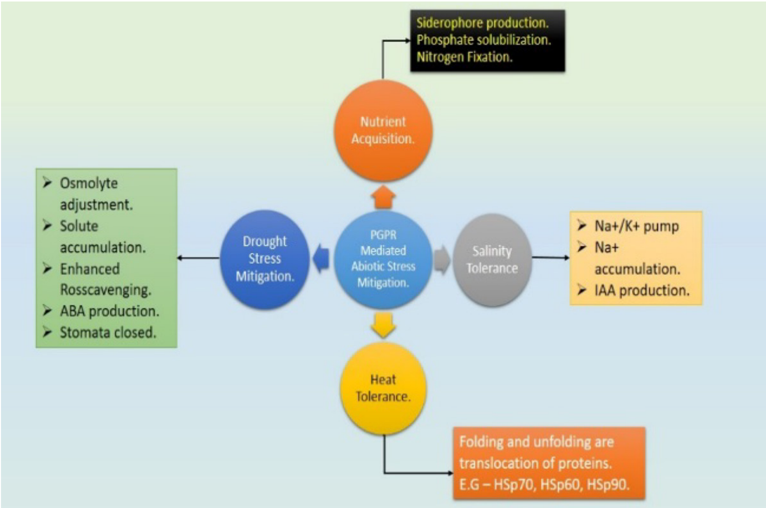

Fig. 4. PGPR: A green agro ecological solution for abiotic stress amelioration.

several *Achromobacter* strains are among the symbiotic nitrogen fixers (Pérez-Montao *et al.* 2014. Turan *et al.* 2014, Maxton *et al.* 2017a,b,c,).

PGPR mediates phytohormonal modulation

Root-associated microbes, such as symbiotic or endophytic bacteria, play a significant role in the production of plant growth hormones (phytohormones), which have an impact on seed germination, the development of root systems for better nutrient uptake, the development/elaboration of vascular tissue, shoot elongation, flowering, and overall plant growth (Maxton *et al.* 2018a,b, Antar *et al.* 2021a). Several research point to the possibility of hormone-based growth stimulation and improved plant stress tolerance. The hormone class known as auxins is crucial for the growth and development of plants. The most prevalent and physiologically active phytohormone in plants, indole acetic acid (IAA), is involved in both up- and down-regulating gene expression.

The production of plant growth hormones (phytohormones), which affect seed germination, the development of root systems for improved nutrient uptake, the development/elaboration of vascular tissue, shoot elongation, flowering, and overall plant growth, is greatly influenced by root-associated microbes, including symbiotic or endophytic bacteria (Antar *et al.* 2021a). Microbe-produced plant growth regulators, which have effects similar to those of exogenous plant phytohormonal treatments, can be used to modify hormone levels in plants (Turan *et al.* 2014). Similar to plant-produced phytohormones, microbe-produced phytohormones like auxins and cytokinins control plant hormone levels, regulating photosynthetic processes to foster plant growth and development, and triggering defensive responses against pathogens (Backer *et al.* 2018). IAA is produced by shoot apical meristems of plants and is present in practically all plant tissues as free/diffusible auxins (Maheshwari *et al.* 2015). More than 80% of rhizospheric bacteria are said to be able to produce and release auxins. Sometimes a single bacterial strain can create IAA via many pathways (Kashyap *et al.* 2019). IAA levels in the roots may need to be balanced and regulated in order for plants to respond to salt stress more effectively. The accumulation of certain solutes, such as proline, sugars, polyamines, betaines, polyhydric alcohols, and other amino acids, leads to PGPR-mediated plant osmolytes homeostasis and is crucial for maintaining turgor-driven cellular swelling to withstand osmotic stress brought on by drought and high soil salinity (Vurukonda *et al.* 2016). Osmolytes released by PGPR operate in concert with those made by plants to preserve plant health by enhancing plant growth and development (Sandhya *et al.* 2010) results in overall increased yield without disturbing soil micro biota.

CONCLUSION

Because of its great nutritional value, particularly its protein level, chickpeas are known as the poor man's meat. A detailed morphological and genetic description of the materials to be employed as parental material in breeding operations should serve as the foundation for future selection of novel cultivars. By combining the benefits of PGPR and CRISPR/Cas9 technology, researchers can achieve synergistic effects in improving chickpea's resilience to abiotic stress and climate change. PGPR can enhance the expression of stress-responsive genes edited using CRISPR/Cas9, resulting in improved stress tolerance and overall crop performance. The utilization of PGPR and CRISPR/Cas9 technology in chickpea breeding programs has the potential to accelerate the development of stress-tolerant varieties with increased yields, improved nutritional content, and reduced environmental impacts. Continued research, collaboration, and responsible implementation of these tools can contribute to sustainable agriculture and global food security in the face of changing climatic conditions.

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