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# INFLUENCE OF ABIOTIC STRESSES ON THE PRODUCTION AND SUSTAINABILITY OF RICE CROP

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## ABSTRACT

Rice is a major staple and vital food after wheat, which is consumed globally on a daily basis. However, due to drastic climatic variation, its production is severely impacted by abiotic stresses including drought, salinity, nutrient deficiency, overly submergence, temperature fluctuation and heavy metal stress. Although plants have well-developed defensive mechanisms of stress tolerance, still they are badly affected. According to estimation about 20% of irrigated land is salt affected. Rice is tolerant to salt stress, but their yield losses are higher in low lands than in upper land, mainly due to ionic imbalance and osmotic stress. It is semi-aquatic but prolonged submergence has a lethal effect on plant development and yield. Temperature is another major limitation in rice production, a 1% increase in temperature causes a 10% reduction in yield under dry season. Globally, drought slashes national cereal production by 9-10%, causing up to 28% yield losses during critical growth stages, exacerbated by high-temperature stress. Furthermore, precipitation variations lead to significant production reductions. Heavy metal contamination poses health risks and disrupts ecosystems, with over 53 metals reported in plants, none with prescribed roles. These stresses manifest in various forms, including nutritional disorders, delayed flowering, panicle abnormalities, infertility, and reduced photosynthesis, ultimately culminating in severe yield losses. To address these challenges, diverse management strategies have been deployed. Genomic studies have provided insights into the molecular mechanisms underlying stress tolerance, identifying key genes and pathways involved in stress perception, signal transduction, and stress response regulation. High-throughput sequencing technologies, such as RNA sequencing and genome-wide association studies (GWAS), have enabled the identification of stress-responsive genes and genetic variations associated with stress tolerance traits. Additionally, functional genomics approaches, including gene editing technologies like CRISPR-Cas9, have facilitated targeted manipulation of stress-related genes to enhance plant resilience against abiotic stresses. Complementary molecular, physiological, biochemical, and agronomic techniques offer promising avenues to bolster stress tolerance and reinvigorate rice production sustainably, minimizing economic losses.

***Keywords***: Rice, Abiotic stress, Agronomic techniques, Genomic and management approaches

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## 1. INTRODUCTION

Unlike, other living organism plants are sessile as they cannot move away from the changing environment to protect themselves. Therefore, plants that have efficient defense mechanism survive while other faces severe damage to yield and other traits and some become dead due to the drastic effects of the changing environment (Zafar et al. 2021). Half of the world's population regularly consumes rice, which is a necessary cereal in the food. Besides wheat, it is considered the 2nd most significant grain crop around the world (Haroon et al. 2022a). It has a good nutrient profile and is liked by most of the population around the world. Due to its sensitive nature, rice faces several abiotic stresses which lower the yield and damage the plant badly. Under the contemporary climate change scenario, abiotic factors such as heat, salt, drought, heavy metals, and nutrient shortage are to blame for the sharp decline in rice yields (Arif et al. 2019).

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The abiotic stresses act as a limiting factor in rice production. Most abiotic stresses are related to submergence and drought, soil problems like salinity and nutrient deficiency as well as temperature extremes (hot and cold temperature). These stresses harm the growth and productivity of rice (Defoer 2002).

Soil salinity causes greater output losses in low-lying areas as compared to the upper land. Most crops are sensitive to salt stress when it comes to rice. Rice experiences a 10% reduction in yield even at an electrical conductivity (EC) level of 3.5 $dSm^{-1}$, with yield dropping by nearly 50% at an EC of 7.2 $dSm^{-1}$. Despite being a glycophyte plant, rice growth is impeded when subjected to salt stress (Razzaq et al. 2020). Two different kinds of stressors are brought on by salinity for plants: Ionic and osmotic stress. High Na+ ion concentration causes significant issues for the plant in many aspects of its life, including delayed flowering, poor panicle development as a result of partial or whole grain loss, sterility, and decreased photosynthetic activity, all of these contribute to yield reduction (Thorat et al. 2018).

Since rice is a semi-aquatic plant, it can withstand excessive watering. However, prolonged submersion harms the growth and yield of the plant. It has an impact on the plants' morpho-physiological development (Hasanuzzaman et al. 2018). Submergence affects the photosynthesis of the plant, increases the susceptibility to different diseases and pests, decreases nutrient availability, and ultimately makes the plant weak to survive (Nishiuchi et al. 2012).

Temperature stress in rice is another major limiting factor. Rice shows a negative correlation with the temperature rise. The rice plant has been more susceptible to high temperature at flowering stages. It causes a decrease in the fertility of the spikelet and in some cases even leads to no harvest. It causes pollen sterility, inhibition of anther dehiscence, and no germination of stigma. The pollen tube does not elongate which causes sterility due to heat stress (Karapanos et al. 2010). Whereas the plant at low temperature at the heading stage is given poor grain development. The pollen viability decreases which results in low grain production. Low temperature causes male sterility as the tissue loses its function (Gothandam et al. 2007). The present review will focus on several abiotic stresses, their effects, and strategies to overcome those effects.

## 2. SALINITY

According to estimates, salt stress has harmed farmed land by up to 50% during the first half of the twenty-first century and reduced plant productivity by about 20% of irrigated land worldwide. (Zafar et al. 2023a). Rice plants under salt stress have slower development, more metabolic alterations, and a reduced capacity to absorb nutrients and water (Munns et al. 2002). The damaging outcome of salt stress is a buildup of sodium chloride (NaCl) in plant tissues and soil (Nishimura et al. 2011). Plant cells absorb soluble salts ($Na^+$ and $Cl^-$) from the soil, causing an ionic imbalance that can disrupt plant physiology (James et al. 2011). Salinity also contributes to nutrient imbalances. For example, increased sodium intake might decrease plant uptake of potassium, which is necessary for plant growth (Farooq et al. 2022). Additionally, reduced nitrogen uptake during salt stress has been noted (Abdelgadir et al. 2005). Subsequent research revealed that these circumstances have a counteracting influence on phosphorous, potassium, zinc, iron, calcium, and manganese in rice crops, but a combined effect on nitrogen and magnesium (Jung et al. 2009). Under such circumstances, cell division and elongation are substantially inhibited, which lowers rice plant production and root and leaf growth (Munns, 2002). It has been observed in many experiments that salinity during the fertility stage may be the source of panicle sterility which results in a decrease in the setting of grain, bearing capability of pollens, and reduction of stigmatic surface (Abdullah et al. 2001). Due to salt stress rice leaves chlorophyll and carotenoids concentration are severely reduced.

## 3. SUBMERGENCE

Water is essential for plant growth, however, too much water during submersion or water logging can be harmful or fatal. The plants that are covered with water or up to the terminal part are said to be submerged (Catling, 1992). The adverse impacts of submergence are many. Plants exposed to submergence experience reduced light stress, limited gas diffusion, soil mineral outflow, physical injury, and increased susceptibility to diseases and pests (Greenway and Setter, 1996; Ram et al. 1999). But in the case of rice plants, these have adaptations to tolerate submerged conditions. The formation of aerenchyma which is the connection between shoots and roots and permits aeration is one of the characteristics (Armstrong, 1980; Colmer, 2003; Colmer and Pedersen, 2008). Additionally, gas films present in the leaf are tiny layers having trapped air to permit aeration internally in darkness and entry of carbon dioxide in the time used during photosynthesis to improve tolerance against submergence in rice crops (Pedersen et al. 2009). It has been found that low-land cultivars of rice instead of having these traits for aeration are still not tolerant to submerged conditions so to reach the air-water boundary their leaves and stems tend to elongate

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moderately but this results in the depletion of energy reserves and ultimately death of plant when depth and period of flooding are extended (Bailey-Serres et al. 2010).

## 4. DROUGHT EFFECT

Drought is defined as a decrease in plant water contents, reduced turgor loss, closure of stomatal pores, lower leaf water potential, and ultimately decreased cell development (Jaleel et al. 2009; Zafar et al. 2023b). Drought stress disturbs rice grain production globally and this situation is becoming worse with the increasing population rate (HongBo et al. 2005). A favorable environment is necessary for crop growth but in some cooler areas, drought reduces 9-10% of cereal production worldwide. In developing countries, rice cultivation is not as important for food security but also a source of income generation (Krishnan et al. 2011; Haroon et al. 2022b) and almost half of its production is affected by water deficiency problems across the world (Bouman et al. 2005). Plant survival is significantly impacted by drought, and results in the decreased photosynthetic rate of plants owing to an irreversible injury in plant development (Oh-e et al. 2007) and ultimately plant death may occur in severe water-deficient conditions (Jaleel et al. 2009). Its adverse effects on respiration, ion uptake, translocation of nutrients, and carbohydrate metabolism are also reported (Farooq et al. 2008). In response, the plant decreases its leaf area and also modifies the sucrose translocation pathway between sources and sink organs (Farooq et al. 2008). Spikelet sterility and improper grain filling occur when water deficiency arises during plant vegetative growth and flowering (Acuña et al. 2008). Grains under drought stress have a negative association with soil water content (Mukamuhirwa et al. 2019). The initial phase of drought has an impact on the rice crop's morphology, biochemistry, physiology, and results in produce reduction (Pandey and Shukla 2015).

The drought condition caused a decrease in the rice yield among different rice genotypes. Drought-sensitive rice genotype Swarna Sub1 showed a greater decrease in rice yield than drought-tolerant genotypes NDR 97 and Nagina 22 (Singh et al. 2018). When drought stress is applied during the vegetative and blooming stages of plant growth, it causes a rice yield loss of upto 20% at the vegetative stage and 28% at the flowering stage (Babu et al. 2003). Zhang et al. (2018) described that there is almost a 21-50% reduction in the rice yield at the vegetative stage, 42–83.7% at the flowering stage, and 51–90.6% reduction during the complete plant reproductive stage under moderate to severe water-deficient conditions. The physiological activities of plants do not recover to their initial form at the grain-filling phase with the formation of chalky kernels and when the rice crop is in its flowering stage, there is a water deficit and a decrease in rice output (Yang et al. 2019). In comparison to the yield drop during grain filling and the vegetative stage, the flowering stage drought caused a 50% reduction in rice output (Sarvestani et al. 2008). Reduced plant water potential also led to a decline in tillering, panicle count, grain production, and plant cell division (Zhang et al. 2018).

## 5. TEMPERATURE EFFECT

The usual temperature for rice production optimally ranges between 25-35°C but this production is impressive in temperate regions due to the provision of a limited period for its proper development (De los Reyes et al. 2003). Seedling growth is promoted at a temperature range from 21-33°C because the chemical variations dominate at this temperature (Krishnan et al. 2011). The calculation of about one percent raised temperature can cause a 10% decrease in rice production in dry seasons (Peng et al. 2004). In essence, the degree, rate of increase, and duration of temperature stress on plant performance determine the effects of high temperatures on plants (Wahid et al. 2007). The decrease in precipitation and increase in temperature are positively correlated with rice productivity (Mahmood et al. 2012). High temperature ranges from 40-45°C is applied for a period of 6h and reduction in seed set, grain quality, and rice yield is observed among 169 accessions showing varying tolerance to temperature stress. Moreover, this decline is more severe in the vegetative phase than in the booting phase (Cheabu et al. 2018). It has been discovered that in rice crops, the flowering phase is the most vulnerable to high temperatures. It resulted in a reduction in spikelet fertility due to aggravation in the degeneration of spikelet and distortion in the development of rice floral organs (Wang et al. 2019).

Since rice is a cold-sensitive plant, low temperatures during the reproductive phase of plant growth harmed yield and other yield characteristics (Farrell et al. 2006). The length of the leaf sheath increased due to high humidity, plant height, and leaf blade width but also caused a diminution in root length, length of leaf blade, number of plant roots, rate of leaf emergence, and production of plant dry matter as plant yield (Hirai et al. 2000). A decrease in temperature triggered a decline in panicle development, seedling growth, panicle exertion, spikelet fertility, heading, and grain quality (Hirai et al. 2000). When low-temperature stress occurred at the vegetative phase, it resulted in reduced seedlings vigor and delayed plant growth. It also affected the phonological stage, grain production, economic yield in rice crops, and lower spikelet fertility during anthesis which also led to declining in grain yield stability (Zeng et al. 2017). At 13°C temperature for fifteen days at the flowering stage in rice crops, a decrease in the number of plant panicles, length of panicles, the total number of grains, and grain yield is reported

(Ghadirnezhad and Fallah, 2014). It is further explored that cold-tolerant cultivars showed enhancement in the number of rice germinated pollen and pollen grains than that of cold-sensitive rice cultivars (Zeng et al. 2017). The increase in precipitation from 5 to 15% in October and September harms the growth of rice, ranging from 5.71 to 15.26% (Mahmood et al. 2012).

## 6. PRESENCE OF HEAVY METALS IN SOIL

The amount of heavy metals in soil is rising quickly as a result of human activity. Heavy metals have a detrimental effect on plant growth. Heavy metal toxicity disrupts a plant's ability to function normally by altering the cellular and protein structures of the plant and disturbs the cytoplasmic membrane which ultimately affects the photosynthetic, the plant's enzymatic processes and respiration (Emamverdian et al. 2015). Through their roots, the heavy metals are absorbed by the plants and end up in their food, which poses serious health risks when eaten. When heavy metals find their way into the food chain, they affect humans as well as animals. The morphological and physiological effects caused by heavy metals are the same as the other abiotic stresses (Dubey et al. 2014).

53 elements are reported as heavy metals among natural elements, and these play no useful function in the plants (Shahid et al. 2015). Heavy metals like Cadmium, Nickel, Chromium, and mercury are commonly as these are present in wastewater released from the industries. Among this cadmium is the most dangerous one as it gets absorbed by the roots. Its toxic level is almost 20 times greater than the other metals. Cadmium damages and changes the physical structure, function, and biochemical features (Zeng et al. 2015).

Aluminum is known as a growth inhibitor if present in high concentration. It initiates growth when present in less concentration but inhibits it in high concentration. It damages the plant's roots, making it difficult for the plant to absorb nutrients from the soil. As a result, the plant becomes nutrient-deficient, which lowers output. Manganese is essential for several plant functions, including photosynthesis and respiration. Manganese may move from roots to the upper portion of a plant with ease (Soceanu et al. 2005). That's the reason that the toxicity caused by it is shown more in the crop's apical portion.

Given the diverse and dynamic nature of abiotic stresses, there is a pressing need for the development of stress-tolerant rice varieties through conventional breeding approaches as well as advanced biotechnological tools such as marker-assisted selection and genetic engineering. Additionally, agronomic practices such as improved water management, soil amendments, and crop diversification can help mitigate the impacts of abiotic stresses on rice crops and enhance their resilience to environmental challenges (Zafar et al. 2024). The production of ROS in rice plants occurs primarily in response to environmental cues associated with abiotic stresses. For example, drought stress disrupts cellular water balance, leading to the overproduction of ROS through mechanisms such as photosynthetic electron transport chain dysfunction and the activation of NADPH oxidases. Similarly, salinity stress disrupts ion homeostasis, leading to ROS generation via oxidative burst reactions and the inhibition of antioxidant defense mechanisms in rice tissues (Zafar et al. 2024). The detrimental effects of ROS on rice yield are multifaceted and affect various aspects of plant physiology and metabolism (Fig. 1). Excessive ROS accumulation can damage cellular structures such as membranes, proteins, and nucleic acids, leading to membrane lipid peroxidation, enzyme inactivation, and DNA damage (Manan et al. 2022). Furthermore, ROS-induced oxidative stress can disrupt essential metabolic processes such as photosynthesis, respiration, and carbon assimilation, ultimately leading to reduced biomass accumulation (Zafar et al. 2022b), impaired reproductive development, and decreased grain yield in rice crops.

## 7. Modern Biotechnological Tools for the Development of Abiotic Stress-Tolerant Rice

### 7.1. Metabolic Engineering/Transgenics

Rice varieties that are resistant to abiotic stress are developed by boosting the synthesis of abscisic acid (ABA), which is required for plant stress management. OsbZIP72 transcription factors play a vital role in drought and osmotic stress tolerance via ABA-mediated signaling (Baoxiang et al. 2021). miR529a targets the OsSPL2 and OsSPL14 genes, increasing tolerance to oxidative stress. In rice plants, OSLI-1 regulates the production of stress-sensitive genes as well as panicle growth. Arabidopsis thaliana has an established pyrabactin resistance profile (Yue et al. 2017). Overexpression of PYL orthologs in rice confers tolerance to cold and drought. Transgenic rice that expresses JERF1 is more drought-resistant (Yadav et al. 2020). EDT1/HDG11 increases grain yield while also conferring drought tolerance. Due to the presence of the antioxidant enzyme MnSOD, rice plants are resistant to droughts. Salinity stress may arise from the removal of sodium ions via the plasma membrane's Na1/H1 antiporter pathway (Mishra et al. 2023). The overexpression of the yeast SOD2 gene in rice plants results in enhanced photosynthesis and reduced production of reactive oxygen species. ABA may activate JERF1. Salt stress tolerance is enhanced in the rice species Oryza sativa by introducing the PpENA1 gene from Physcomitrella patens. In response to abiotic stress, rice with overexpressed OsECS gene exhibits improved germination rate and redox balance. CYP734As uses C-22 hydroxylated brassinosteroid intermediates as substrates. In rice plants' responses to abiotic stress tolerance, miR160, miR168, and miR169 have significant functions (Nounjan et al. 2012).

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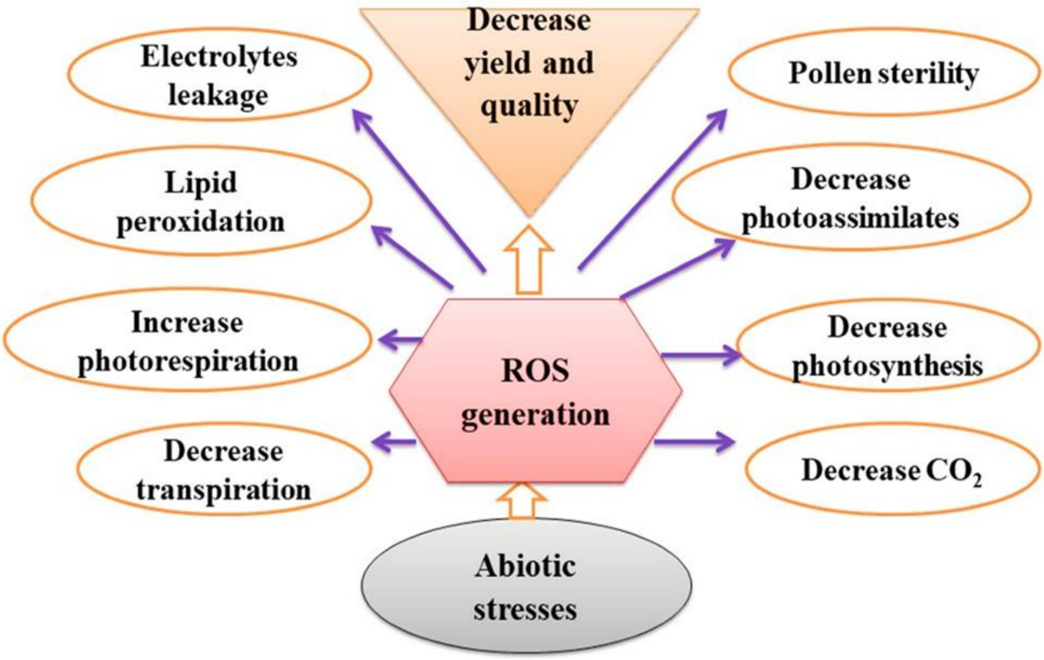


**Fig. 1:** The effect of abiotic stresses on rice plant's physiological traits, yield and quality (Alkharabsheh et al., 2021).

### 7.2. Marker-assisted Breeding

To feed the world's growing population, it is critical to develop high-yielding, sustainable rice cultivars that can survive abiotic stresses. Traditional breeding concerns can be easily identified and resolved with DNA marker-assisted technologies. To select for abiotic stress tolerance in rice, marker-assisted breeding processes have been developed using molecular markers such as amplified fragment length polymorphism, restriction fragment length polymorphism, quick amplification of polymorphic DNA, and simple sequence repeats (SSRs). Rapid high throughput genotyping with single nucleotide polymorphism (SNP) markers has accelerated the development of molecular breeding applications (Ali et al. 2023).

The genetic underpinnings of rice's resistance to heat, salinity, and drought were discovered using quantitative trait locus (QTL) mapping. This information was helpful for map-based cloning of abiotic stress tolerance genes and MAS in rice breeding. The polygenic inheritance of salt tolerance in rice acts as a bottleneck in traditional breeding, and salinity tolerance poses a serious threat to the world's rice supply. 18 and 32 QTLs were identified by using markers to genotype a set of introgression lines (ILs) from a salt-tolerant donor rice line called "Pokkali" in a susceptible high-yielding rice cultivar called "Bengal" background (Nogoy et al. 2016). In arid and semi-arid regions of the world, breeding for drought tolerance is an important priority since drought has a significant impact on crop quality and productivity. To produce drought-tolerant varieties using MAS techniques, it was required to first understand the mechanisms involved in drought tolerance and then create drought-tolerant variants. One of the biggest abiotic threats to rice yield is heat stress, and most of the studies on the subject have focused on finding QTLs in the reproductive stage of rice (Hassan et al. 2023). QTL regions containing polymorphic SNP markers can be used in the future for fine mapping and to create SNP chips for marker-assisted breeding. Using a 5K SNP array, the rice QTLs for heat tolerance were mapped in 272 F8 RILs that were created from a cross of the heat-tolerant Nagina22 and the heat-sensitive IR64 rice cultivars (de León et al. 2016).

### 7.3. RNAi Biotechnology

RNA interference (RNAi) is a molecular process that uses double-stranded RNAs to induce post-transcriptional gene silencing, preventing some genes from being produced (Ullah et al. 2019). Crops and organisms can be improved and modified using molecular engineering to achieve desired traits such as altered nutrient content, decreased toxic/allergic content, morphological changes, altered male sterility, enhanced secondary metabolite production, and increased resistance to biotic and abiotic stressors (Haroon et al. 2023). Since its introduction by Craig Mello to assess inhibited gene expression in Caenorhabditis worms, RNA interference (RNAi) has been widely used in molecular research on a variety of organisms (Younis et al. 2014).

The main mechanism of RNA interference (RNAi) is the suppression of the target gene caused by small RNA molecules interfering with the translation of messenger RNA (mRNA) transcripts. It has been demonstrated that

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several siRNAs have this function, including miRNAs, repeat-associated siRNA, trans-acting siRNA, heterochromatic siRNA, natural antisense transcript-derived siRNA, long siRNA, PIWI-interacting RNAs, QDE-2-interacting RNA, and small vault RNAs. RNA interference (RNAi)-mediated gene silencing involves three fundamental processes: induction, completion-multiplication, and destruction (Liu et al. 2022). RNA interference (RNAi) technologies have demonstrated potential for improving crop yields, namely in the areas of altered nutrition, morphological modifications, male sterility, secondary metabolite enhancement, and heightened resistance to both biotic and abiotic stresses (Saurabh et al. 2014).

### 7.4. OMICS Approaches

Many omics approaches have emerged as powerful biotechnological tools in recent years for understanding plant responses to abiotic stress and developing abiotic stress-tolerant, climate-resilient plants (Zafar et al. 2022a). These methodologies were used to analyze and correlate differential changes in the transcriptome, RNAome, proteome, and metabolome of the examined plants, resulting in the creation of complete gene networks relating to plant responses to stressful situations (Zargar et al. 2022). Technological developments have enabled the identification of underlying candidate genes for complex abiotic stresses in plants. The sciences of proteomics and metabolomics have grown rapidly, providing detailed and extensive information on the proteins and metabolites produced by plant cells in response to numerous environmental stimuli. These locations are expected to yield improvements in cereal production (Roychowdhury et al. 2023).

Stress tolerance is significantly influenced by regulatory molecules and networks, about which transcriptome profiling provides comprehensive information. High throughput or deep sequencing has been made possible by modern platforms like RNA sequencing, and this has aided in the identification of stress-tolerant candidate genes in agricultural plants (Roychowdhury et al. 2023). Epigenetic mechanisms are crucial regulatory systems that help plants build tolerance and respond to abiotic stressors. The epigenetic regulation of plant responses to abiotic stress has been clarified by advances in epigenomics, with small non-coding RNA species like miRNA serving as important epigenetic regulators of stress responses (Radha et al. 2023). However, additional research is necessary, especially in the area of epigenetics, to understand how important crops, like rice, react to abiotic stress. All things considered, different omics techniques offer precise frameworks for assessing plant responses and adaptation mechanisms, hence encouraging the creation of intelligent, abiotic stress-tolerant crops (Kumar et al. 2019).

### 7.5. CRISPR/CAS

The term CRISPR was coined in 2002, referring to tandem repeats flanked by nonrepetitive DNA stretches initially observed downstream of Escherichia coli alkaline phosphatase isozyme genes in 1987. Demonstrating its significance in genome editing, the technology was first showcased in mammalian cells in 2012. CRISPR-Cas systems serve as natural defense mechanisms in bacteria and archaea against foreign organism invasion (Ali et al. 2023). When the host is invaded, Cas proteins fragment the foreign DNA, integrating these fragments into the CRISPR locus as new spacers. Upon subsequent invasion by the same foreign organism, recognition is facilitated by crRNA, leading to pairing and guiding Cas proteins to cleave target sequences in advance, providing early host protection. CRISPR technology requires a guide RNA (gRNA), a synthetic oligonucleotide sequence of 20 nucleotides binding to target DNA, and a Cas9 nuclease enzyme that cleaves 3–4 bases after the protospacer adjacent motif (PAM), typically 5′ NGG (Kumar et al. 2023). Cas9 comprises RuvC-like and HNH domains, each responsible for cutting one DNA strand. The CRISPR-Cas system is classified into class I and class II, with further subtypes (Fig. 2). Class I systems involve multiple protein subunits and crRNA, while class II systems involve a single protein and crRNA targeting invading viral RNAs. In type II systems, Cas9 processes pre-crRNA with tracer RNA and RNase III assistance, whereas in type V and VI systems, Cas12 and Cas13 proteins process pre-crRNA independently (Fig. 2; Wang et al. 2024).

CRISPR-Cas technology holds immense promise for improving rice under stress conditions. Rice is a staple food for over half of the world's population, but its production is threatened by various environmental stresses such as drought, salinity, and diseases. CRISPR-Cas offers a precise and efficient tool to introduce beneficial traits or edit undesirable ones, thereby enhancing rice resilience to stressors (Nascimento et al. 2023). One approach involves identifying genes responsible for stress tolerance in wild rice varieties or related species and using CRISPR-Cas to introduce these genes into cultivated rice varieties. For example, genes associated with drought tolerance, such as those involved in regulating water uptake and retention or maintaining photosynthetic activity under water-deficit conditions, can be targeted for enhancement. Similarly, CRISPR-Cas can be employed to improve salt tolerance in rice by targeting genes involved in ion homeostasis, osmotic regulation, and antioxidant defense mechanisms (Kim et al. 2023). By precisely editing these genes, researchers can develop rice varieties capable of thriving in saline soils, thus expanding arable land for rice cultivation. Furthermore, CRISPR-Cas can aid in enhancing disease resistance in rice by targeting susceptibility genes or introducing resistance genes from other plant species (Rengasamy et al. 2024). This approach can mitigate the impact of devastating rice pathogens

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such as bacterial blight, blast and sheath blight, contributing to sustainable rice production. Additionally, CRISPR-Cas technology enables the development of stress-tolerant rice varieties tailored to specific environmental conditions. By targeting genes involved in stress response pathways or regulatory networks, researchers can fine-tune rice traits to withstand a range of stressors, ensuring stability and productivity in unpredictable climates. Moreover, CRISPR-Cas offers advantages over traditional breeding methods by enabling precise and rapid trait introduction without introducing unwanted genetic material. This accelerates the breeding process, allowing for the timely development and deployment of stress-tolerant rice varieties to meet the growing global demand for food security in the face of climate change (Ali et al. 2023).

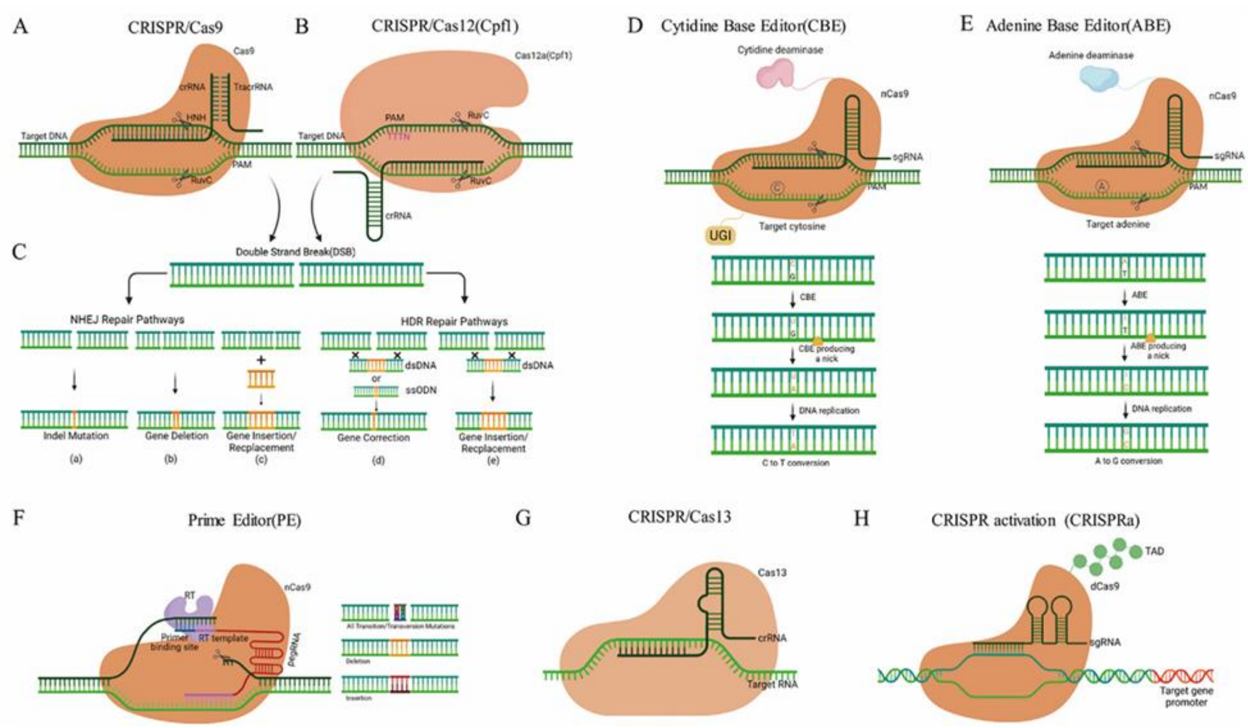


**Fig. 2:** The methodology of major CRISPR/CAS systems (Wang et al. 2022).

## 8. CONCLUSION

Climate change drastically affects agriculture. Abiotic stresses among them are more pronounced such as salinity, drought, submergence, and temperature variation in the world's biggest rice-producing regions. Problems are aggravated due to accumulative stresses, so that's way there is a dire need to opt for a management approach to address the critical problem. Molecular genomics and physiological and biochemical techniques have proven to be authenticated in stress alleviation. Nevertheless, there is a continued interest in how rice crops will respond to future changes in temperature, moisture, and other biotic and abiotic factors as the climate is the consistent feature of the globe and now it is changing day by day as a result of anthropogenic activities. In addition to these techniques, many more recent works have been carried on developing transgenic plants that are more resistant to climatic variation and high yielding under adverse conditions as well. Morphological adaptation, molecular mapping of genes, and marker-assisted genetic breeding programs in integration with genetic modification ought to be coupled to significantly raise plants' ability to withstand stress.

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