**Emerging Plant Hormones: Opening up New Lanes to Face Abiotic Stresses**

**Abstract**

Abiotic stressors such as drought, salinity, extreme temperatures and heavy metal toxicity, represent significant obstacles to global agricultural productivity. Next-generation plant hormones including Jasmonic Acid (JA), Strigolactones (SLs) and Melatonin, have been identified as essential regulators of stress adaptation. These hormones are instrumental in modulating stress-responsive signaling pathways thereby enhancing plant resilience through various physiological and molecular mechanisms. Jasmonic Acid (JA) serves as a vital hormone in plant defense, orchestrating responses to oxidative stress, facilitating stomatal closure and promoting the production of secondary metabolites to counteract drought and salinity stresses. Strigolactones (SLs) influence root architecture and symbiotic relationships, thereby improving water and nutrient absorption in nutrient-deficient and saline environments. Melatonin, recognized for its potent antioxidant properties and role as a signalling molecule, mitigates oxidative damage, optimizes photosynthetic efficiency, and boosts tolerance to abiotic stress through interactions with abscisic acid (ABA) and auxins. The application of advanced biotechnological tools, such as CRISPR/Cas genome editing and nanoparticle-based hormone delivery systems, presents new opportunities for refining hormone regulation in crops. A comprehensive understanding of the interactions between JA, SL, and melatonin with other plant hormones will facilitate the development of stress-resilient crops. These cutting-edge strategies hold significant potential for improving agricultural productivity and sustainability in response to the stresses induced by climate change.

**Keywords**: Abiotic stress, Plant hormones, Resilient, Agricultural productivity, Jasmonic Acid,Melatonin, Strigolactones

**Introduction:**

“Plant Growth Regulators (PGRs) are chemicals that regulate growth, development, and other physiological processes by  upregulating or downregulating certain components. PGRs can be either natural or man-made. PGRs affect or regulates one or more physiological processes. Various PGRs  have different sites and actions in  different plants. PGRs are divided into two groups based on how long they have been utilized in the horticulture industry. Some PGRs have been successfully harnessed and are commonly used by farmers such as gibberellins, abscisic acid, ethylene, auxins, and cytokinins” (Kumar et al., 2024; Vashi, 2023; Margay et al., 2024). “For plants, biotic and abiotic stressors have a significant impact on growth and development. Drought, salt, water logging, heat, cold, and heavy metal stress are examples of abiotic variables” (Zahid *et al.,* 2023; Salam *et al.,* 2022; Afridi *et al.,* 2019; Salam *et al.,* 2022). Osmotic stress brought on by drought stress leads plant cells to be dehydrated, which ultimately kills the plant [Salam*et* *al., 2022;].* Additionally, plants' osmoregulation mechanism is severely harmed by salinity. The growth and species distribution of numerous plant communities are impacted by waterlogging stresses, also referred to as flooding stress (Voesenek *et al.,* 2004). Plant development is adversely affected by heat and cold stressors. Because it impacts plant growth and development, which in turn affects food safety and security, heavy metal toxicity is the most concerning of them. Metals and metalloids classified as heavy metals are generally greater than 5 g/cm3 [Hawkes., 1997]. When these metals are taken up and absorbed by the roots of plants, they can lead to a variety of issues for the plants, including unbalanced electrolytes, electron transport chains, and altered redox homeostasis [Sirhindi *et al., 2020*]. The health of plants and people is seriously threatened by the constant shifting global climate. Therefore, to overcome environmental issues and to protect food security and food safety, it is imperative to contend with changing climatic conditions [Wang, F *et al., 2019;* Oshita, *et al.,* 2023; Munir, *et al.,* 2023;]. Plant Metabolic pathways, such as REDOX activities, which enable them to generate their food energy in the form of ATPs, are often necessary for growth and development [Ahmad *et al.,*2020;]. However, the presence of heavy metals in the soil, such as copper, arsenic, zinc, cobalt, chromium, manganese, etc., eventually disrupts plant metabolism, which inhibits plant growth [Zeeshan, *et al*., 2023; Azhar, *et al*., 2023; Khan, *et al.,* 2021; Yang, *et al*., 2021; Zeeshan, *et al*., 2021; Salam, *et al*., 2023;]. Due to their extremely insoluble nature, these heavy metals persist in the soil for extended periods. Heavy metals enter through roots during the water uptake process cells into the xylem, impeding metabolic processes in plants and ultimately resulting in cell death [Piotrowska*, et al*., 2009;]. It is well known that phytohormones control plant growth and development and promote stress tolerance in response to the aforementioned challenges. One of the most important hormones among them is jasmonic acid (JA), which plays a part in plant signaling pathways that can cause physiological and biochemical changes and assist plants in reducing the deadly impacts of different abiotic stresses [Zuo, *et al*., 2023;]. The precise function of endogenous and exogenous JA in protecting plants from abiotic stressors has been the subject of numerous investigations. However, comprehending the intricate mechanisms governing the synthesis and operation of plants is an extremely difficult process with many complex steps and molecular pathways. The production of JA is carefully regulated by the activation of many gene activities. We still don't fully grasp the underlying processes that underlie this activity, though. However, it is crucial to gain a thorough understanding of JA, especially its function in promoting stress tolerance. Gaining a thorough understanding of JA production, its mechanism of action, and its real-world applications is the main goal of this review. As part of our review, we will go into more details about the intricate mechanisms, production, and functions of JA in preventing several abiotic stressors.

**Effects of abiotic stress on horticultural crop productivity**

Plants encounter a variety of stressors throughout their life cycles, beginning with seed germination (Figure 1). Numerous abiotic stresses reduce crop productivity and quality, which results in crop loss products, such as stressors caused by heat, drought, salinity, and nutritional deficiencies (Andreotti, 2020). Abiotic stressors cause morphological, physiological, and biochemical changes in products, which affects not just yield but also product quality (Rao *et al.,* 2016). Horticultural crops face several abiotic challenges due to recent changes in the climate. Another major issue facing the agriculture sector in the future is the changing climate (Gao *et al*., 2022; Francini and Sebastiani, 2019; Shahid *et al*., 2021). Plants have been shown to exhibit a variety of stress responses, such as a decrease in the production of photosynthetic machinery, leaf water potential, membrane integrity, photosynthetic pigments, yield and plant growth (Ullah *et al.,* 2018). Additionally, 90 percent of agricultural fields are affected by one or more stressful situations. As a result, the horticulture industry is constantly looking for innovative agronomic instruments that can counteract the negative effects of environmental conditions while preserving the production's overall sustainability and quality.

(Source: Zheng et al., 2023)

Fig 1: A variety of stressors are encountered by plants throughout their life cycles

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(Source: Zheng et al., 2023)

**Jasmonic Acid-Mediated Abiotic Stress Responses:**

“Plant tolerance to abiotic stress is tightly linked to the plant signalling chemical jasmonic acid. JA often plays a role in physiological and molecular reactions to abiotic stress. The antioxidant system (superoxide anion radical, peroxidase, etc.) is frequently activated as part of physiological reactions. NADPH-oxidase)”[Karpets, *et al*.,2014] buildup of soluble carbohydrates and amino acids (isoleucine and methionine)[Wasternack, *et al*., 2014], and control of stomatal opening and closure[Acharya, *et al.,* 2009]. JA-associated genes (JAZ, AOS1, AOC, LOX2, and COI1) are expressed [Hu,Y.R *et al*., 2017; Robson, *et al.,* 2010], interact with other plant hormones (ABA, ET, SA, GA, IAA, and BR) [Ku, *et al*., 2018; Yang, *et al*., 2019], and interact with transcription factors (MYC2 and bHLH148) [Zhao, *et al*., 2013; Seo, *et al*, 2011]. Figure 2 illustrates potential JA pathways in abiotic stress tolerance. The function of JA signalling in controlling plant responses in various settings is covered in this section.

Fig 2: Illustrating the potential JA pathways in abiotic stress tolerance



(Source: Jia Wang, *et al*., 2020)

**Cold Stress:**

“Plant growth and development are significantly hampered by low-temperature stress, which also has a significant impact on the geographic spread of plants. Low-temperature stress, which is defined as plant damage brought on by temperatures above and below zero, can take two different forms: chilling stress and freezing stress. C, in that order” [Huang, *et al*., 2014; Trischuk, *et al*., 2014]. “In order to stabilize the ensuing cell membrane damage, plants have developed sophisticated tolerance mechanisms against such stressors, such as the activation of hormone-related genes and the accumulation of proteins, amino acids, and soluble carbohydrates linked to cold-induced stress”[Hincha, *et al*., 2014]. “Genes involved in JA biosynthesis, such as lipoxygenase2 (LOX2), allene oxide synthase1 (AOS1), and allene oxide cyclase (AOC), can be expressed under low-temperature settings. In order to improve cold tolerance, jasmonic acid upregulates the transcriptional pathway for C-repeat binding factor (CBF), which in turn positively influences downstream cold-responsive genes” [Hu, *et al*., 2017]. “Recent research on Bananas has demonstrated that during cold storage, two MYC2 TFs are quickly activated by the exogenous administration of MeJA. Furthermore, MeJA dramatically increases the expression of genes involved in the cold-responsive pathway that promotes CBF expression (ICE-CBF)” [Zhao, *et al*., 2013]. These results show that, in concert with MaICE1, the MaMYC2 transcription factor contributes to MeJA-induced chilling tolerance in banana fruit. Furthermore, exogenous JA therapy can boost antioxidant production and decrease lipoxygenase activity to improve plants' resistance to cold. Boost antioxidant production and lipoxygenase activity to improve plants' resistance to cold. Furthermore, Lietal.[Li, *et al*., 2018]observed that “the expression of CBF, late embryogenesis abundant (LEA), and dehydration-responsive element binding (DREB1), as well as ABA and JA concentrations, rose in Zoysia japonica under chilling stress”. Additionally, Cao et al. (2009) discovered that “during the storage of MeJA-treated loquat fruit, the activities of the enzymes superoxide dismutase (SOD), catalase (CAT), and ascorbate peroxidase (APX) rose whereas lipoxygenase activity fell”.

**Drought Stress:**

“Global warming and increasingly frequent and/or severe drought episodes in many significant agricultural regions throughout the world are being caused by climate change. One of the main causes of crop yield loss and even crop failure is the effect of drought stress on crops, which can cut yields from several crops by more than 50%” [Abdullah, *et al*., 2015]. Suppressed plant growth [Sun, *et al*., 2017; Javed, *et al.,* 2011], decreased photosynthetic rates [Huang, *et al*., 2017], and hastened leaf senescence [Munne-bosch, *et al*., 2004; Ma, *et al*., 2018] are the overall effects of drought stress. Furthermore, oxidative reactions, membrane lipid buildup, and the production of antioxidant enzymes can all be brought on by drought stress [Lei, *et al*., 2008; Wang, *et al*., 2014]. “By controlling stomatal opening and shutting in Arabidopsis thaliana, jasmonic acid can reduce water loss” [Savchenko, *et al*., 2014]. “The concentrations of endogenous JAs increase rapidly following drought stress, and then return to the baseline levels if stress periods are extended. Furthermore, during drought stress, a large number of genes and transcription factors linked to drought stress are expressed. In the JA signalling pathway, jasmonate ZIM-domain proteins (JAZ) function as regulators, usually repressors”. OsJAZ1 has been shown by Fu et al. [Fu*, et al*., 2017] to have “a negative regulatory function in rice drought stress tolerance, specifically with regard to the ABA and JA signaling pathways. Additionally, OsbHLH148, a basic helix–loop–helix protein”, was discovered by Seo et al. [Seo*, et al.,* 2011] to function as a transcriptional regulator and upregulate OsDREB1 and OsJAZ, which are implicated in the JA signalling pathway and drought stress responses, respectively. Additionally, Ge et al. [Ge*, et al*., 2010] found that “temporary JA buildup in a genotype of Prunus armeniaca that is drought-tolerant may enhance plant survival under soil drought conditions, encourage leaf senescence, and stop excessive water loss. On the other hand, P. armeniaca damage linked to drought stress may be mitigated by the exogenous administration of JAs. MeJA applied topically to soybean leaves can improve their ability to withstand water stress, and additional research revealed higher concentrations of sugars, phenolic compounds, and flavonoids” [Mohamed, *et al.,* 2017]. These results suggest that plants' ability to withstand drought stress is influenced by both endogenous and exogenous JAs.

**Salt Stress:**

Plant metabolism is disrupted by salt stress, which can result in oxidative stress, genotoxicity, membrane problems, and malnourishment [Syeed, *et al*., 2011; Kadri, *et al*., 2014]. Plants' ability to withstand salt stress can be improved by both endogenous and exogenous JA [Domenico, *et al*., 2019]. Changes in tomato cultivars' endogenous JAs during salt stress were examined by Pedranzani et al. [Pedranzani*, et al*., 2003]. Their results showed that salt stress tolerance, not JA production, was linked to the variation in lipid kinase activity between the two salt-tolerant cultivars under investigation. According to Abouelsaad et al. (2018), endogenous JA improved tomato salt tolerance mostly by maintaining balance among reactive oxygen species (ROS). Nevertheless, other research has shown that exogenous JA treatments enhanced photosynthetic rates, proline contents, ABA levels, and antioxidant enzyme activity [Bandurska, *et al*., 2003; Walia, *et al*., 2007] to lessen salt-induced damage to a variety of plants. Possibly by decreases in the rates at which Na+ accumulates in shoots [Khan, *et al*., 2012]. By reducing Na+ uptake, exogenous JA was found by Shahzad et al. (2015)to enhance Na+ exclusion in the root and promote surface salt stress resistance in two genotypes of maize. JA levels rise during the initial stages of salt stress and may play an indirect role in the suppression of leaf development in genotypes that are susceptible to salt. According to Qiu et al. (2014), sthree days of exogenous JA treatment dramatically reduced the levels of hydrogen peroxide (H2O2) and malondialdehyde (MDA) in wheat seedlings, increasing the plants' resistance to salt stress. Transcript levels and the activity of SOD, peroxidase, CAT, and APX also increased dramatically. These findings suggest that by raising the levels of antioxidant molecules and antioxidant enzyme activity, JA may help people tolerate salt stress.

**Heavy Metal Stress**

In addition to polluting the environment, heavy metals hinder the growth and development of plants [Zhang, *et al.,* 2018]. When *Suaeda glauca* and *A. thaliana* were subjected to elevated levels of lead (Pb), nickel (Ni), cadmium (Cd), and manganese (Mn), their fresh weight and concentrations of photosynthetic pigments both dropped. Even at very low concentrations, many of these metals may be harmful to plants and serve no useful purpose in them [Ali, *et al*., 2012]. Cd concentrations in roots and leaves rose significantly at increasing doses of CdCl2, especially in spr2 plants, according to Zhao et al.'s comparison of Cd stress responses in wild-type and JA-deficient mutant spr2 tomatoes [Zhao, *et al*., 2016]. The findings showed that tomato seedlings' sensitivity to Cd may be increased by a lack of endogenous JA. Furthermore, as stated by Sirhindi et al. [Sirhindi, *et al*., 2015], To increase Glycine max seeding tolerance to Ni2+ stress, exogenous JA administration before NiCl2 stress may be beneficial. Azeem [Azeem, *et al*., 2018] also showed that exogenous supplementation of JA reduced the negative effects of oxidative stress on growth, biomass production, and protein concentrations in Ni-treated plants by further increasing antioxidant enzyme activity. They also showed that JA protected the seedlings by controlling the antioxidant machinery and safeguarding the DNA synthesis of total proteins. In addition to increasing osmotic and antioxidant activity, external JA supplementation may reduce CD accumulation rates in faba bean roots, shoots, and leaves by preventing H2O2 and MDA accumulation [Noriega, *et al.,* 2012]. According to Noriega et al. [Carvalho, *et al.,* 2013], JA activated the antioxidant machinery of glutathione or ascorbate, which in turn decreased the activity of lipid peroxidase. Furthermore, ROS homeostasis may be the only factor regulating the notable rise in HO-1 antioxidant enzyme activity that they saw during heavy metal stress. These results suggest that by controlling their antioxidant systems, JAs control how plants react to heavy metal stress.

**Role of melatonin in plants under abiotic stress:**

**Salinity stress:**

Melatonin has been shown in published studies to reduce abiotic stress in a variety of crop plant species. According to (Yin *et al*. 2019), salt stress increased ROS activity and photoperiod regulation while decreasing chlorophyll concentration and photosynthetic activity. By strengthening plants' antioxidant defense mechanisms, melatonin enhanced photosynthetic activity promoted the growth of green bean seedlings under salt stress and reduced oxidative damage brought on by ROS (Elsayed *et al.,* 2021; Hasanuzzaman *et al*., 2020). According to several research, melatonin is essential for different plant species' adaptation responses to salt stress (Liang *et al*., 2018; Chen *et al*., 2018). Nevertheless, the majority of these investigations are observational, and neither physiological nor molecular study has substantiated the findings (Liu *et al.*, 2020). Melatonin increased salt stress in rice by facilitating K+ retention (a crucial part of plant tissue tolerance mechanisms) in the roots of plants and by facilitating the process that needed ROS signalling dependent on Oryza sativa (OS) respiratory burstoxidase homolog F (OsRBOHF) to activate stress-responsive genes, which in turn boosted the expression of K+ uptake transporters, especially OsHAK5, in the root tips (Liu *et al*., 2020). Salt stress has been shown to reduce potassium, an element that is crucial for plant growth and development (Chen *et* *al*., 2018; Liu *et al*., 2019). These outcomes are consistent with Huang *et al*.'s (2019) findings. He suggested that stress signalling and plant adaptation to saline stress may depend on the generation of H2O2 mediated by respiratory burst oxidase homolog (RBOH) produced by NaCl. However, because they haven't been carried out on a wide range of plants under abiotic stressors, research on the function of OsRBOHF-dependent ROS signaling in the activation of stress-sensitive genes and enhanced expression of K+ uptake transporters in the root tip of plants is limited. To enhance the uptake of K+ transporter ions in the root tips of various crops under varied stressors, the additional study should concentrate on discovering responsive genes from OsRBOHF-dependent ROS signaling (Yu *et al.,* 2018).

**Drought stress:**

Crop yields decline as a result of drought stress's detrimental effects on plants' morphophysiological and biochemical activity (Chen *et al*., 2019; Singh *et al*., 2015). Oxidative stress is caused by drought stress, which also damages plant cells and impairs antioxidant defense systems by reducing stomatal closure and photosynthetic activity through increased ROS buildup. Since it causes electron leakage, lipid peroxidation, and consequent membrane damage in addition to damaged protein and nucleic acid contents, the buildup of ROS is regarded as a hazard to plant cell viability (Maksup *et al.,* 2014). Plants have evolved several mechanisms to control their development in response to varying environmental stressors in order to avoid this harm (Kim and Kim, 2020). Melatonin, a novel regulator of plant growth, is believed to play a role in drought stress reactions (Zhang *et al.,* 2015; Li *et al*., 2021). Plant morphological activity, particularly that related to leaf growth and the relative water conductivity of maize seedlings, was decreased by drought stress. In the meantime, melatonin treatment greatly increased leaf size and relative water conductivity (Li *et al*., 2021). Ye *et al*. (2016) found that melatonin increased the shoot dry weight and leaf size of maize seedlings, which was a comparable outcome. In plants, physiological processes in leaves, such as photosynthesis, respiration, and transpiration, are maintained by stomata, the opening and closing of which are controlled by complex signal transduction pathways and water balance. In the presence of drought stress, plants regulate their cellular moisture content by regulating stomatal closure and reducing their transpiration rate. However, the density of stomata significantly increases with the contraction of guard cells and deteriorates under drought stress (Xue *et al.,* 2021). In general, the application of melatonin has shown resistance against the deterioration of stomata cells and increased its length and width under drought stress in corn (Li *et al*., 2021). The contrasting results in the study by Li *et al.* (2015), showed, however, that apples' stomatal cell density was unaffected by drought stress. However, the stomata remained open and the turgor pressure remained high due to the exogenous melatonin administration. Distinct plant species may have distinct melatonin regulation mechanisms, which could account for the discrepancy in the results (Li *et al*., 2021). The current research shows that while the amount, effectiveness, and mechanisms of action of melatonin vary among plant species, fewer morphophysiological reactions have been observed in several plants during drought stress.

**Heat stress:**

Elevated levels of heat stress lead to an increase in endogenous melatonin levels, which, in turn, boosts thermotolerance due to melatonin's strong antioxidant properties in plants (Liang *et al*., 2018; Ahammed *et al.,* 2019). A prior investigation on Arabidopsis demonstrated that melatonin raised the seed germination rate from about 30% to 39% in the presence of heat stress (Hernandez *et al*., 2015). The correlation between phytomelatonin production and seed germination has been established, showing that phytomelatonin is produced during the germination of cucumber seeds, with its highest levels occurring 14 hours post-germination (Zhang *et al.,* 2014). However, additional studies on a variety of crops remain necessary. Melatonin enhances the ability to germinate by facilitating the use of soluble sugars and the production of new proteins**.** and increased amylase and a-amylase activities in melon and Limonium bicolor seeds (Castañares and Bouzo, 2019; Li *et al*., 2019). Melatonin considerably lessens the negative effects of heat stress on plant seedlings, according to recent studies. First, because of the high potency of melatonin, it maintained high viability and germination capacity (Hernandez *et al.,* 2015). When plants are exposed to high levels of heat stress, the activities of antioxidant enzymes, such as superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT), are increased (Wang *et al*., 2022), and melatonin inhibits the accumulation of H2O2 (Marta et al., 2016). Genes involved in gibberellin (GA) production, such as GA20ox and GA3ox, are up-regulated in response to melatonin administration. Melatonin also raises the content of GA, especially GA4. Unfortunately, the important gene NECD2, which is primarily involved in ABA biosynthesis, has its expression down-regulated by melatonin (Zhang *et al*., 2014; Li *et al*., 2019). More research should be done on the mechanisms underlying the up-and down-regulation of gene expression in plant cells during heat stress. Additionally, heat stress can upset the antioxidant equilibrium, which leads to the buildup of ROS and peroxidative damage to cell membranes (Sun *et al.,* 2021). The negative effects of heat stress on plant shoot and root growth were reversed in rice and tomatoes when melatonin was applied exogenously (Wang *et al.,* 2018). By controlling redox homeostasis and modifying NO and polyamine production in tomato seedlings, melatonin also lessened the harm brought on by heat stress (Jahan *et al*., 2019). Melatonin-mediated heat stress in Arabidopsis plants was lessened by the heat shock protein HSP90 and heat shock factors, such as HSFA2 and HSFA32 (Shi *et al*., 2015a). According to a study, HSPs stopped tomatoes' heat-stressed cellular proteins from refolding or breaking down denatured proteins (Xu *et a*l., 2016).

**Cold stress:**

“Cold stress is one of the major abiotic stresses that reduces crop growth and yield, especially in temperate zones and highly elevated areas” (Bhat *et al*., 2022). “Plants exposed to cold stress experience changes in various physiological, molecular, metabolic, and Ahmad et al. biochemical activities. Examples include variations in membrane fluidity, metabolism homeostasis, and enzyme activity” (Wu *et al*.,2022). “Photosynthesis is a pivotal plant metabolism process and one that is highly sensitive to cold stress. This is because low temperature hinders many major components of photosynthesis” (Dahal *et al*.,2012). “Chlorophyll content decreases under cold stress, leading to chlorosis in leaves” (Kaura *et al.*, 2022). “The chlorophyll content of leaves provides important information about the effectiveness of physiological processes in plants in plants” (Gitelson *et al.*, 2003). “Plants treated with melatonin had a higher concentration of chlorophyll than non-treated plants under cold stress” (Yang *et al*.,2022). “Plant growth at low temperatures induces the excessive production or inefficient deactivation of ROS, such as H2O2, superoxide anions (i.e., O2-), and hydroxyl radicals (i.e., OH), which in turn can cause injury to plants” (Ghaderian *et al.*, 2015). “In addition, ROS accumulation causes the oxidation of proteins and peroxidation of lipids within plant cells, resulting in reduced plant growth” (Nahar *et al*., 2015). “Several studies have demonstrated that exogenous melatonin can stimulate plant growth in various plants, such as corn, and can promote the germination of cucumber seeds under cold stress” (Kolodziejczyk *et al*., 2016; Posmyk *et al.,* 2009b). “In Arabidopsis plants, melatonin modulates leaf senescence against cold stress” (Shi *et al*., 2015b). “Melatonin applications enhance the resistance of Bermuda grass to cold stress by improving cell membrane stability, and by regulating photosynthesis and metabolic activity” (Khalid *et al*., 2022). “Melatonin played a role as both a first-line defense and an internal sensor of oxidative stress in a study of different species of plants” (Iqbal and Khan, 2022). “For example, in barley, exogenous melatonin can enhance photosynthetic carbon assimilation by improving the plant antioxidant defense systems of organelles under cold stress” (Li *et al.,*2016). “Therefore, the improved performance of primed seeds in terms of seedling growth and germination might be the result of improved antioxidant defense systems under cold stress. However, an understanding of the growth of waxy corn and other crop seeds primed with melatonin in response to cold stress is still limited” (Cao *et al*., 2022).

**Strigolactones:**

**Role of strigolactones under high temperature**

Crops that are resistant to a range of environmental stressors are being developed using SLs. Importantly, SLs have been described as a helpful tool for stress-related events, and their role in some environmental difficulties has been noted (Tariq *et al*., 2023). Unintentional heat waves and global warming are two significant environmental issues that have gained attention recently. Severe climate change may result in temperatures higher than ideal, endangering tree populations and maybe damaging crops. In 2021, Shafqat et al. Long-term or short-term temperature fluctuations may cause stress for the plant, which requires a specific range of temperatures to carry out its physiological (Khan *et al*., 2019) and biochemical functions (Bermudez *et al*., 2021). SLs are advantageous regulators of the body's resistance to heat stress because of their capacity to increase the activity of antioxidant enzymes and the transcription of proteins (Chi *et al.*, 2021). For plants to adjust to temperature stressors, SLs signaling and biosynthesis are crucial (Pandey *et al.,* 2016). The induction of antioxidants in plants is associated with additional defenses against cellular damage caused by temperature stressors. As signaling molecules, SLs serve as both endogenous hormones that control plant growth and constituents of root exudates that promote symbiotic connections between soil microbes and plants.

**Role of strigolactones under drought stress**

“In recent years, the intensity of water-related stresses has increased drastically such as drought and salinity, which significantly impacted the plant’s growth and development. These problems are spreading worldwide due to global changes. Drought being chronic abiotic stress is responsible for approximately 70 % of the potential crop loss globally. With a significant change in moisture levels, drought hinders agriculture production worldwide. A major impact on moisture levels is mainly caused by the current trends of global warming which increases the

intensity of drought. By the year 2050, productivity losses are expected to increase by 30 % due to drought stress. The condition where the transpiration of the plants exceeds the water absorbed by the roots due to insufficient precipitation or groundwater level drop is referred to as drought” (Khalid *et al*., 2022). “When subjected to drought stress the electron transport chain of the plants gets disturbed resulting in oxidative stress and ROS accumulation leading to the damage of essential organelles. The main objective of the agriculture industry is to provide global food security using a sustainable approach. With the growing population, the challenging demand to feed the population requires high-intensity agriculture management” (L´ opez-R´aez, 2015). “Currently, the strategies used to cope with stresses to minimize crop losses are mainly focused on genetic engineering and traditional breeding crops to develop resistant cultivars, which are time-consuming and costly. To achieve the food demand, advancement in enhanced drought-tolerant plants, and finding cheaper and sustainable alternatives are urgently required” (Khalid *et al*., 2022).

**Conclusion**

Plant hormones are crucial for a plant's growth and development and serve as a vital line of defense against abiotic stresses. Hormones alter the growth pattern so that plants can tolerate stress. Numerous hormones, their downstream response factors, related gene networks, and transcription factors are all involved in the plant stress response. Abiotic stress tolerance mediated by phytohormones is largely dependent on the interactions between hormones, whether they are antagonistic or synergistic [Rivero, *et al*., 2010]. It is essential to comprehend how the various pathways governing the stress response interact at the molecular level in order to manipulate them and increase stress tolerance. This is significant because, in the context of a changing global climate, abiotic pressures are becoming more varied, persistent, and intense. Given the limited effectiveness of traditional breeding methods in addressing abiotic stress, plant hormones are a key focus for improved management of this condition. The cultivation of climate-resilient crops can greatly benefit from the involvement of phytohormonal pathways and their intermediaries.

Plant bioengineering methods have helped accomplish this goal; soybeans [Li, *et al.,* 2013], maize [Lu, *et al*., 2013], rice [Zhang, *et al*., 2012 ], and potatoes [Kim, *et al.*, 2013] are a few examples. The hormone-mediated regulatory mechanisms of the plant stress response are being identified using methods such as genome editing, transgenic plants, transcriptome analysis, and next-generation sequencing analysis. Understanding the mechanism of stress tolerance in plants has been aided by transcriptome analysis utilizing microarrays, a survey of transcriptome profiles, and RNA-seq measurements of microRNA levels in stressed plants [Cai*, et al*., 2020]. The CRISPR/CAS system [Osakabe, *et al.,* 2014; Shukla*, et al*., 2009] and specially engineered endonucleases such as zinc finger nucleases (ZFN) or TAL effector nucleases (TALEN; [Osakabe, *et al.,* 2014; Nekrasov, *et al.,* 2013] can now be used to alter genomes in a site-specific way thanks to genome editing technology.

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