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Plant biotic and abiotic stresses combinations and their management: Review article

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Abstract Studying the environmental pressures that affect plant production needs to be prioritized since climate change is the main obstacles to agricultural productivity. There are two types of environmental stresses that affect plants: biotic and abiotic stresses. Both stresses from biotic as pathogens and abiotic as temperature, UV rays, salinity, floods, droughts, heavy metals, etc. reduced the morphological characteristics and yield of the plant. Abiotic stressors can change plant-pest interactions by making the host plant more vulnerable to pathogenic organisms, and weeds, as well as by lowering its capacity to compete with them. The opposite is also true; certain pests may change how plants react to abiotic stressors. The impact of concurrent abiotic and biotic stresses conditions on crop yield is therefore crucially understood through systematic investigations. Additionally, when several stressors occur at once, the effects on plants are highly complicated since they are influenced by a variety of signalling pathways, some of which are antagonistic and may even work against one another. Plants have created a multitude of coping mechanisms to deal with these challenges. Many studies have been conducted to identify and interpret plant assimilate partitioning and stress-tolerant plant genotype, which are critical for understanding the intricacy of a plant's response to biotic and abiotic stressors. In addition, a number of studies have demonstrated that plant nutrition, silicon, microorganisms, microbiome, and plant growth regulators all contribute to increased plant growth, phytohormone synthesis, and the expression of genes linked to the dehydration response and antioxidants—all of which can enhance biotic and abiotic stress tolerance. Utilizing nanoscale goods like nanofertilizer, nanofungicides, nanoherbicides, and nanopesticides. One such innovative technique to increase agricultural output under various biotic and abiotic stress situations is nanotechnology. This review covers a wide range of subjects related to biotic and abiotic stress reactions in plants with a focus on problems and their management.

Keywords: Plant biotic and abiotic stresses, Climate change

Introduction

According to Atafar *et al.* (2009), stress is defined as any internal or external constraints can lessen the capacity of a plant to transform energy into biomass and limit the pace of photosynthetic activity. There are several stresses

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that can affect plants., which fall into two main categories: biotic and abiotic. Any climatic variation or extreme occurrence might alter the ideal environment for plants, resulting in slower plant growth, undeveloped leaves and roots, and decreased agricultural output (Gray and Brady, 2016). Global climate change has accelerated over the past few decades, potentially posing greater risks to agricultural growth, productivity, and yield. Additionally, it helps diseases and pests spread (Scheffers *et al.,* 2016). Determining the nature of these interactions is essential to understanding the effects of combined biotic and abiotic stresses on plants. Mittler *et al.* ,2006; Suzuki *et al.,* 2014) collected the impacts of many abiotic and biotic stressors on plant growth and production into a "stress matrix". This matrix illustrates the potential positive and negative effects that various stressor combinations may have on plants. Therefore, to create plants with higher resilience to abiotic stresses, it is vital to identify physio-morphological traits that are affected by combined forces. Therefore, it is crucial to look at how crop plants react to the unfavourable environment in the face of these ongoing and rapid changes in climate. In this article, we give a comprehensive overview of various stressors, combinations, and how they are managed in relation to agriculture crops.

Principal stressors that affect plants

Biotic and abiotic stresses

Biotic stress

They are brought on by other living things, such microorganisms as pathogens, bacteria, fungus, live outside influences like plants and weeds, animals, insects, and so on. A plant's growth and health can be significantly impacted by a number of diseases, including bacteria, viruses, and fungi. These infections can cause a range of symptoms, such as wilting, discoloration, and even plant death. In addition to causing diseases , pests such as insects, mites, and nematodes may cause significant damage to plants by feeding on plant tissue, blight leaves, stems, and even roots. These stresses have an impact on the harvest season and directly reduce nutrient uptake. Biotic stress can have negative impacts on a plant's growth and development, such as reducing biomass, impairing photosynthesis, and changing morphology (Haggag and Ali, 2019; Saijo and Loo, 2020). This typically results in the synthesis of protective substances such phenolics and alkaloids, which can impair the nutritional value of crops.

Abiotic stress

Abiotic conditions inclde salt, drought, floods, heat and cold stress, irradiation, tropospheric ozone, nutritional imbalance, xenobiotic stress, etc. can have a detrimental effect on plant growth and productivity (Haggag and Ali, 2019; Hartmann *et al.,* 2022). The majority of plants are susceptible to temperature stress, and they suffer when temperatures exceed certain limits. As an illustration, high temperatures harm the body's metabolism and physiology. Plants either stop growing or freeze in cold weather, eventually dying.

- **Low temperature:** Plants require a specific range of temperatures to grow. Plants stop growing when the temperature lowers significantly because their cellular activity and uptake of nutrients slows down (Jones, 2021). Plants slowly become malnourished and die if they don't receive enough nutrition. While some plants have adjusted, their production isn't as high as it could be.
- **High Temperature:** There is solid reason why global warming is a heated topic. Managing the production of crops is getting harder as the global temperature rises. Plants produce less as a result of diminished food reserves and water loss when temperatures rise (Liliane and Charles, 2020).
- **Stress due to an inadequate or overabound of light.** Photosynthesis, which directly contributes to the synthesis of carbohydrates and oxygen, is powered by light. Each plant has specific requirements for sunlight and light, and these elements may affect the growth and development of a plant.
- **Stress caused by over or unsufficient nutrients.** Of course, nutrients are necessary for plants to grow and produce fruit, but they can also have a negative impact when present in excess, as is the case with nitrogen and phosphorus.
- **Stress from salinity.** An excess of salts in the soil or groundwater due to natural or man-made processes, such as rock weathering, the use of salt-rich irrigation water in irrigation schemes, or inadequate drainage, causes salinity (He *et al.,* 2018) When plants are exposed to a balanced mixture of earth and fertiliser, they grow. The presence of too much salt in the soil or irrigation water might cause this kind of stress. These saline issues may also be caused by inadequate irrigation management. Moreover, salt increases the difficulty of the body absorbing important minerals like potassium and calcium. The reason for this is that salt obstructs the natural flow of nutrients in water. Salt stress primarily affects crop plants via osmotic stress and ion toxicity. Numerous subsequent impacts, including as decreased cytosolic metabolism, decreased cell growth, and assimilate production, are caused by these early effects of salt stress (Fahad *et al.,* 2017).
- **Stress from water.** Water stress is one of the most prevalent stressors and a major cause of plant death. Crop development and productivity are impacted

by plants' inability to transfer nutrients from the roots to the leaves in the absence of water (Gull *et al.,* 2019). In addation, there is an imbalance between transpiration and water absorption. However, too much water in the medium might result in a sequence of shocks that restrict the plant's ability to grow due of a lack of oxygen. There are two ways that water stress might occur. The first is a drought, while the second is waterlogging. The soil does not have enough moisture during a drought to transfer nutrients from the roots to the leaves (Grime, 1977). Plants need their roots because they affect how they develop. As a result, plants stop growing vertically and start producing roots that can absorb nutrition. Conversely, waterlogging, or an abundance of water, makes it difficult for oxygen to be absorbed.

- **Oxidative Stress:** All living things, especially plants, are chemically interacting with oxygen. Oxidative stress is one type of stressor that is both biotic and abiotic. Reactive oxygen species (ROS) are overproduced, which causes this stress. Plants may suffer harm from an increase in free radicals (highly reactive molecules with unpaired electrons) in the environment.
- **Chemical plant stress**: Chemical plant stress is the strain brought on by the physical environment's chemical conditions, such as water, pesticides, air pollution, heavey metals, toxic and soil pH (Rauwane and Ntushelo, 2020).

All of these elements have the potential to cause modifications either accidentally, purposefully, or as a result of metabolic activity. The range of biotic and abiotic variables affecting plants is illustrated in Figure 1.

The impact of stress combinations on plants

Different types of stress interactions can affect plants in different ways, depending on the kind, strength, and duration of the stressors (Figure 2). Most combinations of abiotic-biotic stress and certain combinations of abiotic-abiotic stress entail interactions between the stressors and the plant both inside and outside the plant interface. Interactions between plants can have a range of outcomes. Mixtures of stress caused by heat and drought are instances of such intricate connections. For example, *Avena sativa* (oats) and *T. aestivum* are more sesetively to *Puccinia* spp. as temperatures rise, in contrast to *Cynodon dactylon* (Coakley *et al*., 1999). Agriculturally significant stress combinations include interactions between heat and pathogens and drought and pathogens. Pautasso *et al.*, (2012) have talked about the effects of coupled heat and pathogen interaction on plants. The necrotrophic fungus *Rhizoctonia bataticola* causes dry root rot, a serious disease that is known to be made worse by hot weather and settings when there is a water deficit. Sharma and Pnde (2013), who infected *C. arietinum* plants grown at different soil moisture levels with this fungus, demonstrated the interaction between *R. bataticola* and drought stress in a lab environment. Powdery mildew and charcoal rot are two major illnesses that are greatly impacted by coexisting drought circumstances (Haggag, 2018 and Haggag and Ali., 2019). It is possible to identify and generate superior cultivars if a mechanistic knowledge of the interaction between pathogen and drought stress is obtained.

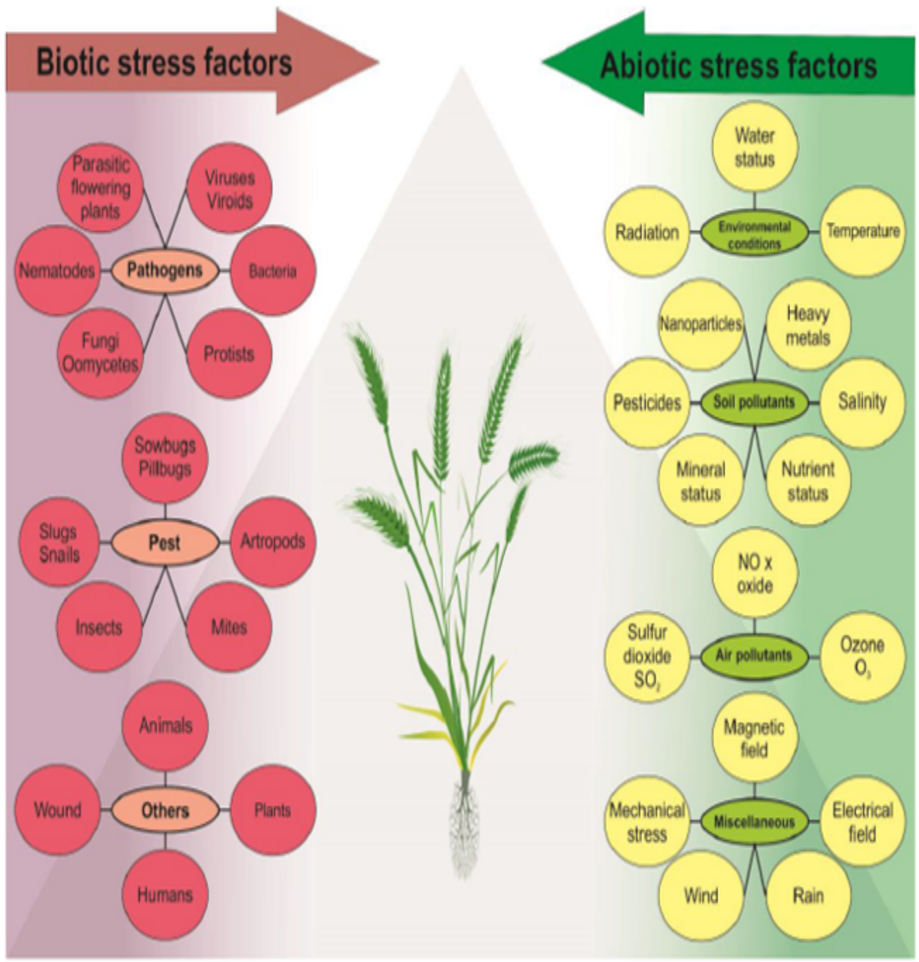

Figure 1. Explains how a variety of environmental elements may stress plants, including biotic ones like diseases, pests, and direct effects on people and animals, as well as abiotic ones like weather fluctuations, soil and air pollution, and magnetic fields. These stressors have the potential to upset a plant's homeostasis, stop it from growing, and have an impact on the growth of both developed field crops and wild populations. (Georgieva and Vassileva, 2023)

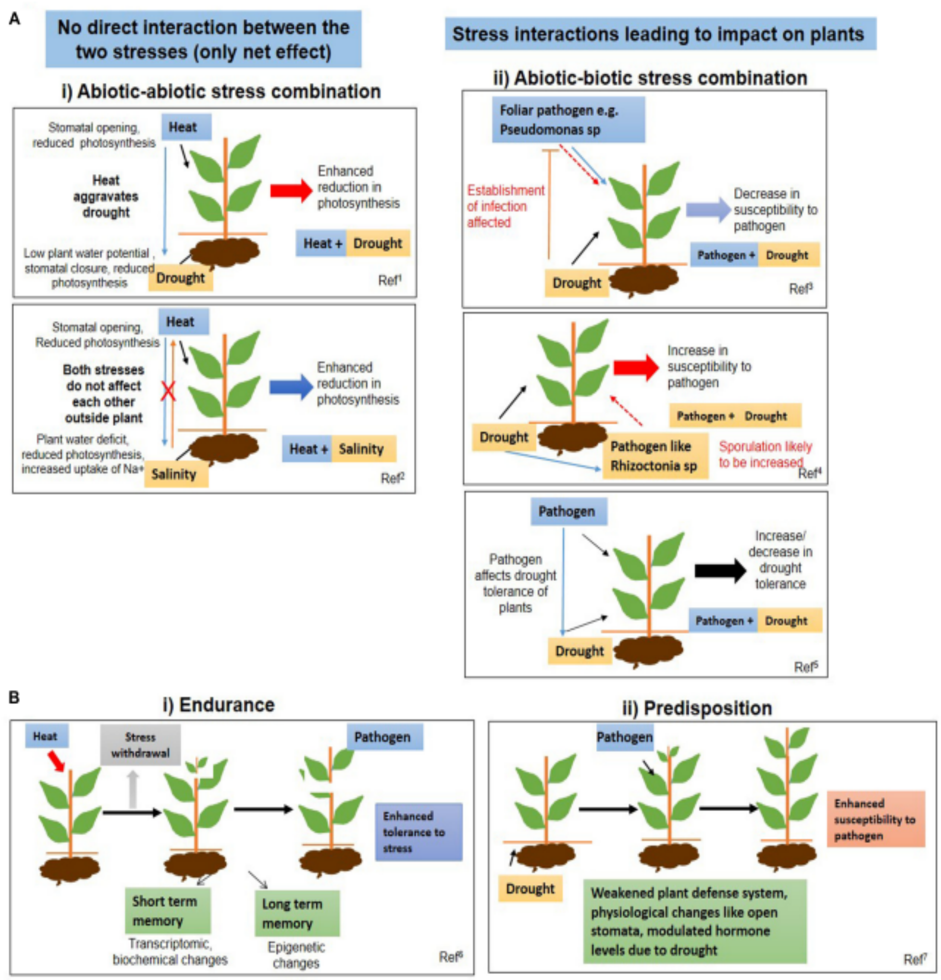

Figure 2. An example of how stress and other factors work together to affect plants. (A) By utilising the examples of heat and drought (abiotic-abiotic stress) and drought and pathogen stress (abiotic-biotic stress), we can demonstrate how combined pressures affect plants. (i) Even if the two stresses do not come into physical touch with one another, they may interact at the plant-to-plant interface and negatively impact the plant as a whole, depending on the type of stressors. It is common to specify "only net effects and no stress interactions" in relation to abiotic stress combinations. For instance, prolonged exposure to salt and heat inhibits physiological processes such as photosynthesis. When one stress component influences another, there are evident stress interactions in both biotic and abiotic stress combinations (Mittler, 2006)

Strategies for biotic and abiotic stress management in plants

The methods for enhancing crop performance under stress and combination biotic and abiotic stresses have been discusses. The management strategy used by farmers and agronomists heavily incorporates plant stresses. Farming and agricultural research have led to a rise in the number of stressors studied. This implies that although the list of plant stressors might be long, knowledge of them can be beneficial to a farm's performance.

Plant tolerant

Plants experience significant biotic and abiotic stressors because they are sessile, unlike other living things. Plants have evolved a wide range of efficient defence mechanisms that are fueled by external factors like shock duration and intensity as well as inherent ones like developmental conditions and genotypic and phenotypic makeup. Stress management incorporates molecular and biochemical level controls that alter the speed and efficiency of a stress signal's interpretation and transmission, which in turn produces stress signal molecules and activates stress-protective mechanisms. Plant competence allows for a wide range of adaptive responses to biotic and abiotic stressors at the morphological, physiological, biochemical, and molecular levels. To increase plant productivity in challenging environments, genetic modifications of signalling networks have been frequently exploited. Agriculture may be sustained sustainably with the use of advanced biotechnology applications. Several metabolic and molecular pathways implicated in plant responses to varying environmental conditions have been identified and reported by recent study. As hundreds more metabolic pathways are discovered, it is becoming increasingly evident how polyamines help plants cope with stress and improve their ability to acclimatise and adapt. In this respect, Rangan *et al.,* (2014) state a relevant overview of our understanding of polyamine production and catabolism and highlight recent advancements in clarifying the roles of polyamines in regulating plant responses to abiotic stressors. The improved stress tolerance might subsequently be achieved by using the genotypes that have suitable allelic variations.

According to Saddique *et al*. (2018), the intensity, and ability of plants to activate the appropriate defence mechanisms all affect how they react to biotic stress. Plants react to external stressors by initiating many hormonal pathways. The Jasmonic acid (JA) pathway plays a major role in plant defence against necrotrophic fungus and some bacterial infections. When these stressors exist, plants respond by producing JA, which initiates a cascade of signalling connections that ultimately lead to the activation of genes relevant to defence and the production of specialised metabolites including phytoalexins and protease inhibitors. (Saddique *et al.,* 2018). Another important phytohormone that is essential for plant defence against biotic stress is salicylic acid (SA). Additionally, phytohormones like auxin, brassinosteroids, gibberellins, cytokinins, abscisic acid (ABA), and peptide hormones are also implicated in modifying plant immune responses (Saddique *et al*., 2018).

According to Ku *et al*. (2018), JA is one of them that interacts with other phytohormonal pathways and is important in activating the plant defence system. In reaction to external stimuli, plant cells go through a variety of physiological changes. The quality of the harvested products may suffer as a result of these reactions, which might alter the phenology, growth, reproduction, and chemical composition of plants. However, the effects of various external stressors on plant development and physiological systems vary according to the stress's intensity, any concomitant stressors, the plant's genotype, and its growth stage. The primary effects of these pressures on plants' morphophysiological and biochemical traits are reductions in growth and yield. These consequences include decreased leaf area, changed root development, stomatal conductance, membrane instability, reduced photosynthetic activity, and altered oxidative metabolism and water relations. However, a plant's genetic makeup, ability to withstand stress, and a variety of environmental factors all affect how it responds to stress overall. Plant tissues and organs work together via chemical signals to adjust to adverse environmental circumstances. Stress sensing, signal transduction, and plant stress tolerance molecular networks are activated in a way that controls the expression of some stress-related genes and the production of stress-related enzymes. A significant part of the evolution of plants' stress tolerance mechanisms is also attributed to their increased antioxidant defence system.

Nutrients in stresses management

Potassium, sulphur, iron, manganese, zinc, and copper are the minerals that are most crucial for controlling plant stress. Plants need a healthy, balanced diet. Plants can absorb much more of these nutrients under stressful conditions. The proteins and enzymes produced by these nutrients are utilized to manage stress and control plant physiology. Under stresses plants can alter their physiological processes in an effort to boost nutrient intake by altering their root systems. This include modifying the angle of the roots, encouraging the formation of lateral roots or root hairs, or developing microbial connections with mycorrhizae. Foliar nutrients have been demonstrated to strengthen and advance root systems. In times of stress, "super-oxides" (complex oxygen compounds) can accumulate in the plant. Plants can produce antioxidants to combat this.

Some of the essential minerals needed to produce these antioxidant enzymes, which aid in the plant's ability to cope with stress, are manganese, iron, copper, zinc, and sulphur.

Silicon

Numerous studies have examined the impact of silicon on biotic and abiotic stress, as well as overall plant growth and development. In both agriculture and the natural world, silica plays a critical and quantitatively important role in the soil-plant system (Epstein, 1994). It is only recently that Si's potential as a fertiliser for crop performance or as a plant protectant in an integrated disease/pest control approach is beginning to be commercially appreciated. This element is crucial to a plant's survival in numerous ways, but it is particularly effective in reducing biotic and abiotic stressors. With a few exceptions, the following generalisations regarding Si may now be drawn based on the research that has been done thus far: (1) For a plant disease to be suppressed, its tissues must contain a minimum amount of silicon (Si); (2) disease suppression will increase proportionately as the amount of Si in plant tissues increases; (3) the effects of disease suppression must be continuously supplied to the plant roots; and (4) only plants that have received this supply of silicon will be able to suppress disease. The physiological, biochemical, and molecular reactions of plants to pathogen infection, insect assault, and even abiotic stress will only alter when Si is delivered to the roots; (5) Si will impact several elements of host resistance, including the number of lesions, incubation time, and latent duration; (6) Si may boost a cultivar's resistance to foliar diseases in specific rice and sorghum cultivars; and (7) Si can suppress disease just as well as fungicides (Datnoff and Rodrigues, 2015). According to Fortunato *et al*. (2015), Fusarium wilt on cucumber and lettuce, Fusarium root rot on melon, Phytophthora root rot on avocado and soybean, and Phytophthora blight on bell pepper are the most important soilborne diseases that Si has been demonstrated to be able to manage. Pythium root rot can cause bitter gourds to become brown, maize to turn yellow and creeping bentgrass to develop brown patches and dollar spots due to Pythium root rot. When compared to the roots of non-supplied Si plants, the histochemical studies of banana plant root sections showed strong flavonoid deposition in the sclerenchyma and metaxylem vessels in response to *F. oxysporum* f. sp. cubense infection (Figure 3). (Fortunato *et al.,*2014).

Role of plant growth regulators in stresses tolerance

Organic substances known as plant growth regulators (PGRs) are substances that regulate different stages of plant growth and development. They are not nutrients. PGRs serve as secondary stress messengers, which they do to a significant extent in the mitigation of various abiotic stress situations. Five broad plant defense-related compounds that offer defence against abiotic stressors have been found by He *et al*. (2018). These include the cuticle, which serves as an outer barrier; suitable solutes; reactive species scavengers; unsaturated fatty acids (UFAs), which operate as a membrane modulator and oxylipin precursor; and molecular chaperones, which stabilise proteins and subcellular structures. Numerous upstream signalling molecules, such as phytochromes, calcium, reactive oxygen species, hydrogen sulphide, polyamines, reactive oxygen species, stress PHs, and transcription factors, are part of a complex regulatory network that controls these protective metabolites (He *et al.,* 2018). Auxins, salicylates, ethylene, cytokinins, gibberellins, jasmonates and abscisic acid are among the nine categories of PHs that have currently been identified (Su *et al.,* 2017).

Omics technologies

The study of biotic and abiotic stresses responses in plants has benefited greatly in recent years from the development of omics technologies (Ibraheem *et al*., 2018). Omics tools have greatly enhanced and protected crop quality, leading to higher agricultural food production, by improving the nutritional value, flavour, and quality of food crops. The time and expense needed to produce better food crops that are resistant to stress factors and exhibit a high nutritional value have decreased thanks to omics technologies such as genomics, transcriptomics, proteomics, metabolomics, and bioinformatics. This has made modern plant breeding more consistent and predictable (Ibraheem *et al*., 2018). Plants have developed a variety of physiological, metabolic, and biochemical defence mechanisms to withstand biotic and abiotic stresses. According to Chawla *et al.* (2011), plants have evolved complex signal transduction pathways for a variety of stress circumstances, but it is often difficult to predict when these pathways will become active or dormant. We are able to fully comprehend the structure and dynamic function of a molecular system thanks to the four main axes of plant system biology approaches: transcriptomics, proteomics, metabolomics, and genomics (Yuan *et al.,* 2008). Compared to a single gene analysis, this approach provides a more comprehensive platform for researching biological processes as a complex network. The creation of new cultivars with improved stress tolerance is essential to controlling global climate change and meeting future food demands. Hence, regulating plant stress requires the integration of omics technologies.

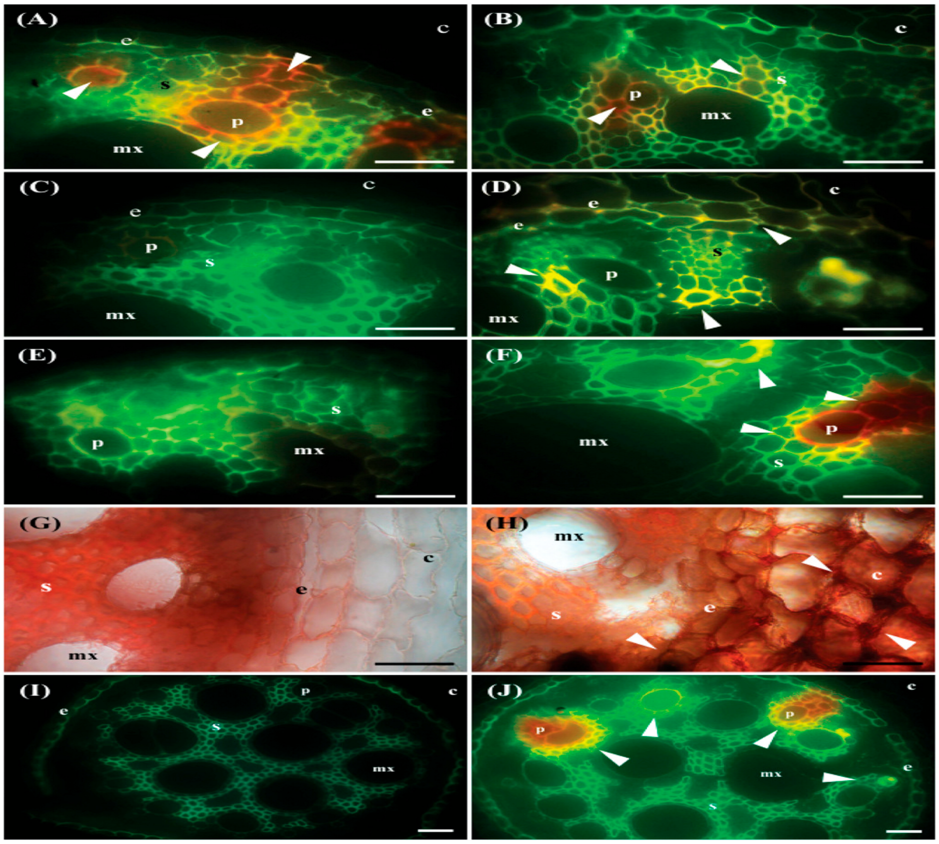

Figure 3. The presence of flavonoids, lignin, and dopamine in the roots of banana plants from the cultivar "Maç" were assessed by histochemical analysis 32 days following the plants' inoculation with Fusarium oxysporum f. sp. cubense. Vascular bundles and sclerenchyma cells in the roots of -Si plants exhibit strong yellow-orange autofluorescence (arrow). B, The phloem and metaxylem vessels in the roots of +Si plants have a modest yellow-orange autofluorescence (arrow). C,Neutron-stained roots of Si plants show no fluorescence in the vascular bundles, sclerenchyma, or endodermis cells. +The D, Neu's reagent-stained roots of Si plants exhibit a prominent yellow fluorescence (arrow). E, Transparent orange-yellow, reproduced with permission from Fortunato *et al.* (2014)

Microorganisms, bioelicitors and microbiome

Various microbial populations interact with plants, and they have intricate connections with one another. Plants are protected from a many biotic and abiotic obstacles thanks to the close relationship between microorganisms and their host. Symbiotic, parasitic, or mutualistic plant-microbe connections all revolve around plant-microbe interactions. By promoting natural processes, microorganisms provide plants their resistance to outside pressure. Biostimulants, bioelicitors also known as biofertilizers, are substances that assist plants recover from stress by increasing their tolerance to it against biotic and abiotic stresses (Haggag, 2016 and Haggag *et al*., 2017). Stronger plants result from the biostimulants that promotion of root growth and improved nutrition and water absorption.

The most efficient instrument that might be used to help agricultural plants develop their resistance to abiotic stimuli and contribute to adaptation techniques is microorganisms. The most efficient way that plant-growth promoting rhizobacteria (PGPR) reduce the effects of abiotic stressors (drought, low temperature, salt, and high temperatures) on plants is by producing production of bio films and exopolysaccharides (Chakraborty and Niharendu Saha, 2019). Since bacteria make up the majority of the microorganisms in soil, some of them that are observed colonizing plant roots are referred to as PGPR. The improvement of plant development under stressful situations has been linked to a variety of bacterial families. Research has demonstrated that PGPR, including *Paenibacillus polymyxa, Achromobacter piechaudi, Azospirillum brasilense, Pseudomonas* sp.*, Burkholderia and Bacillus,* can improve the tolerance of drought in drought-stressed (Trivedi *et al.*, 2020; Ali and Khan, 2021). According to Adedayo *et al.* (2022), microorganisms utilise biochemical and molecular pathways to help plants connect with bacteria in order to counteract the detrimental effects of abiotic stressors on plant growth. To change the way a plant's roots look, auxins, cytokinins, and gibberellins are some of the phytohormones that make a difference (Arkhipova *et al.,* 2020), which alters how well plants adapt to environmental stresses like salinity, nutrient deficiency, heavy metal exposure, and drought. Hormones such as auxins are produced in response to stimulation of root cell elongation and lateral root formation. These processes improve the plants' capacity to take up water and nutrients. To lessen the negative consequences of abiotic stress, PGPR used induced systemic tolerance (IST), which comprises the following interventions. Examples of phytohormones include the synthesis of auxin, abscisic acid (, and cytokinin; the degradation of the ethylene precursor; and the release of different antioxidants, including glutathione reductase andp eroxidase, which catalyse the transformation of oxidised glutathione into reduced glutathione through the ascorbate-glutathione cycle (Misra and Chauhan, 2020). Furthermore, plants' ability to adapt to a range of environments, including those that are vulnerable to abiotic stressors like salt, cold, drought, heat, toxic metals, and flooding, has been related to fungus (Poveda *et al*., 2020). Using bio elicitors like *Acremonium coenophiulum, Streptomyces griseus, Trichoderma harzanium, T. viride,* *Rhodotorula glutinis,* and *Paenibacillus polymyxa* and natural elicitors like methyl jasmonate, chitosan, ascorbic acid, and putrescein improved two wheat varieties, cvs. Gemmiza and Skaha, were able to withstand the stresses of an arid climate (Haggag *et al.*, 2017). Endophytes and Arbuscular mycorrhiza are diverse communities of microorganisms that reside inside the host tissue without displaying any outward symptoms of infection and are involved in stress tolerance. However, they share many functional characteristics with other rhizospheric bacteria, including the ability to acquire nutrients, modulate phytohormones, synthesise bioactive chemicals, and produce antioxidant enzymes (Pathak *et al*., 2022). They are nevertheless superior to other microbes due to their greater capacity for colonisation and resistance to abiotic stress (Pathak *et al.,* 2022). These fungi give stress tolerance by altering the host plant's physiological, biochemical, and nutritional traits. These include siderophore overproduction, proline buildup, sodium absorption inhibition via increased uptake of electrolytes like K, improved uptake of root water, and increased antioxidant capacity (Diagne *et al*., 2020). The endophytic strain has recently been used with effectiveness against biotic stress. It has been discovered that endophytes, such as *Fusarium culmorum, Curvularia protuberata, Phoma glomerata, Penicillium* sp*., Paecilomyces formosus and Trichoderma*, confer resilience against abiotic stimuli and stress (Haggag *et al*., 2017 and Okon *et al.,* 2020). The endophytic bacterium *Lactobacillus Plantarum* has been shown by Chen *et al*., (2020) to have biocontrol capability both an in-vitro investigation and an in-vivo experiment on *Botrytis cinerea's* mycelial growth. The pathogen *Monilinia fructigena* was successfully controlled by Madbouly *et al.* (2020) using various endophytic yeast strains.

More in-depth research is required to determine whether and how selective breeding influences the microbiomes of contemporary industrial systems. Therefore, it is crucial to explain the origins of the related microorganisms as well as their species (Nevo, 2012). Future agricultural research will benefit greatly from a comprehensive knowledge of the plant-microbe connection, which includes the molecular processes, signal transduction, genetic foundation, and underlying gene activities. It is clear that concentrating on microbial-plant interactions can result in viable approaches to developing ecologically sustainable production systems and goods that enhance biotic and abiotic stress management, promote food quality, disease prevention, and plant health, as well as the restoration of soil health. Microbiome products, also called biostimulants or biofertilizers, are any material or microbe given to plants with the express purpose of enhancing feeding efficiency, abiotic stress tolerance, and/or crop quality features. Plant communities use their microbiomes to form and evolve.

Nanoparticles in plants   stresses management

Nanoparticles, such as Zn NPs, Ag NPs, SiO2 NPs, Cu NPs, Fe NPs, Mn NPs, C NPs, Ti NPs, Ce NPs, and K NPs, were effective in reducing the detrimental effects of salt stress in a range of plants (Zulfiqar and Ashraf, 2021). Cerium-oxide nanoparticles have been shown to improve photosynthetic activity and improve mineral absorption by changing the root cells of Brassica napus (Khan *et al*., 2020). In addition to improving plant roots' hydraulic conductivity and water absorption to boost their resilience to drought stress, NPs show a differential abundance of proteins implicated in oxidation-reduction, ROS detoxification, stress signalling, and hormone pathways in plants (Kandhol *et al.,* 2021). Examples of metal-oxide nanoparticles that have been shown to be effective in boosting the physiological and metabolic activities of plants under drought stress include iron oxide (Fe3O4), titanium dioxide (TiO2), and zinc oxide (ZnO) (Alabdallah *et al.,* 2022). Along with nanofertilizers, it was shown that greenly synthesised Fe3O4 NPs were effective in reducing the effects of drought stress on fenugreek plants (Bishta *et al*., 2022).

Chitosan nanoparticles have been shown to be effective in lowering photosynthetic activity, electrolyte leakage, and membrane damage in chickpea plants subjected to cold stress via transcriptional regulation (Amini *et al.,* 2017). Similar to this, SiNPs can enhance sugarcane plants' capacity for photosynthetic activity while they are under stress from cold (Elsheery *et al.,* 2020). By using Fe3O4 NPs, the amount of Cd metal that is available in soil has been decreased (Wang *et al*., 2020). In plants, flooding stress has been shown to be reduced by nanoparticles. Similar to this, it was shown that Zn nanoparticles could improve wheat's resistance to heat stress by boosting the synthesis of antioxidant enzymes and lowering lipid peroxidation (Hassan *et al*., 2018).

Applications of nanosilica, generated from the algae Blue-green Cyanobacteria - Oscillatoria agardhii, improved wheat resilience to biotic stress, such as illnesses, environmental stress, and the quality of the soil and irrigation water (Haggag *et al.* , 2018). Under normal circumstances, this led to a reduction in crop losses and an increase in agricultural yield in some semi-arid locations. Treatment with blue-green algae resulted in an increase in antioxidant enzymes such as catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD). Additionally, there was a general rise in grain yield, flour protein, and glutamine, as well as an improvement in wheat yield quality indices.

Conclusion

The increasing need for food to support a growing population and the continued need for global food security prevent agricultural production from rising due to environmental pressures. These stresses have significantly harmed the global agri-cultural sector's economy in addition to reducing crop output. Plants have developed sophisticated defensive mechanisms to fend off environmental challenges and guarantee their survival in the face of a range of hardships (Grey and Brady, 2016). Modifying the structural features of plants to modify their morphology and anatomy might be a strategy to mitigate the consequences of climate change (Bano *et al.,* 2019). One of the key jobs to preserve crop quality and profitability is reducing stress in plants. And achieving that sustainably is an even bigger problem. Plants can adapt to their environment by developing long-lasting resistance, transient resistance, or complete resistance to the stress. There are still ways to encourage plant development if crops haven't evolved to withstand severe conditions. Various approaches have been developed to mitigate these effects, ranging from traditional breeding at the whole-plant level to isolating and transferring resistant genes at the molecular level to enhance crop development. Despite the challenges in these techniques, a simple, low-cost method of using microorganisms has been viewed as a potential, broad-spectrum way of generating the necessary compounds. In particular, under various environmental challenges including infections, drought, and salinity, plant growth-promoting bacteria have several positive effects that can be targeted to maximise agricultural productivity.

Under stressful conditions, microorganisms, microbiome and bionanoproducts improved many plants' morphological characteristics, physio-biochemical and yield characteristics, including chlorophyll content, relative water content, enzyme activity, and grain yield. Understanding these interactions between microorganisms and plants using various molecular and biochemical strategies will enhance their capacity to manage stress. It may be more cost-effective and environmentally benign to use microbial inoculation to treat plant stressors since it would be available sooner.

The creation of crop simulation models that combine both biotic and abiotic challenges can help with disease predictions in locations where the two stressors frequently overlap. The effective creation of combination stress-resistant crops that can perform well under field circumstances requires collaboration between crop modelling specialists, agronomists, field pathologists, breeders, physiologists, and molecular biologists.

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