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Review Article

Plant Response to Biotic and Abiotic Stresses

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Abstract

The main elements influencing agricultural productivity in terms of both quantity and quality are biotic and abiotic stressors. The purpose of this study is to examine how biotic and abiotic stress affect plant productivity and production, as well as to highlight potential plant adaptation strategies. Abiotic stressors that cause crop losses include drought, water logging, salinity, wind, air pollution, heavy metal stress, and severe temperatures such the chilling effect and heat. Similar to abiotic stressors, biotic stressors like disease and insect pests can endanger plants and have an impact on their growth and development. Biologic agents, including bacteria, fungus, viruses, and nematodes, are responsible for the majority of plant illnesses. Notwithstanding their inability to move, plants have highly developed immune systems and are frequently subjected to a variety of stresses, for which they display complex defense mechanisms such as a wide range of physiological, molecular, and cellular adaptations that enable them to endure both biotic and abiotic stressors. Additionally, plants have a variety of morphological traits that are linked to distinct physiological and biochemical pathways for their reactions to various stressors.

Keywords

Abiotic and Biotic Stresses, Biochemical Activity, Plant Response

1. Introduction

The most important factor in maximizing the potential of every crop, regardless of location, is climate. Crop productivity is impacted by climate change, which poses a major challenge to food security. Weather events and the usage of germplasm, which scientists must constantly enhance and replace in order to make it resistant to different biotic and abiotic stresses, have a significant impact on agricultural productivity. In order to produce information that may be used in breeding plans, researchers work to comprehend the route linked to stress responses. Stress in agriculture is a phenomenon that lowers crop productivity [7]. Numerous pressures can have a negative impact on a single organism, a population, or a community. Stress can also be described as the circumstances that impede plants from reaching their full genetic potential for growth, development, and reproduction. Numerous pressures that plants are subjected to on a regular basis significantly lower their yield. Because they are immobile [13], plants are able to have highly sophisticated immune systems. To survive under biotic and abiotic challenges, they also display complex systems that entail a wide range of physiological, molecular, and cellular changes.

2. Abiotic Stresses

Because of climate change and the growing human population, it is imperative that stress-resistant crops be developed.

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There are two ways that climate change affects agricultural output: directly and indirectly. Indirect effects include severe problems with drought and salinity, while direct effects include floods, ozone hole depletion, and glacier melting brought on by rising air temperatures. Abiotic stressors are thought to be responsible for over 70% of crop yield losses. Since agricultural land is becoming scarcer in the modern period, abiotic stress is a major worry for crop development and productivity. Plants build up specific biomolecules that are innocuous and do not affect their productivity in order to adapt to abiotic stressors. Abiotic stressors that limit agricultural product and negatively impact plant growth processes include salinity, drought, alkalinity, flood, cold, heat, various forms of radiation, heavy metals, air pollution, and many more. The main abiotic factors that cause significant crop losses worldwide are drought, salt, and extremely high temperatures.

2.1. Drought Stresses

A period of dryness or a severe moisture deficit below the expected level that severely damages crops and limits their growth and development is known as a water deficit condition. One of the main environmental conditions that negatively impacts crop development and output is drought. In agriculture, drought conditions caused by a lack of soil moisture have a negative effect on crop productivity while it is being grown. The water requirements of various crops are directly impacted by the intensity of the drought stress. The various phases of their growth and development also play a role.

Reduced seed germination and seedling development, poor vegetative and reproductive growth, a decreased rate of photosynthesis, disruption of normal development and growth rate patterns, and ultimately a decreased crop yield are all consequences of low soil moisture. High osmotic pressure and high root pressure are linked to drought resistance, according to a study done [16]. The ability of the sugarcane variety Co 997 to produce new, functioning roots in extremely low moisture circumstances was linked to its resistance to drought. For rain-fed circumstances, it is best to choose root types with low respiration [14]. Under drought stress conditions, plants exhibit a variety of physiological, morphological, and biochemical reactions. These include the accumulation of proline, trehalose, and polyamines, an increase in nitrate reductase activity, and the storage of carbohydrates at the cellular and organism levels. A significant part of drought tolerance is also played by abscisic acid. Drought conditions boost the formation of proline content and its deposition in the leaf tissues. Compared to drought-susceptible cultivars, drought-tolerant varieties accumulated more proline [15]. When compared to the susceptible variety F 146 and the moderately tolerant variety F 160 of Taiwanese sugarcane, proline quickly accumulated and swiftly decreased with the injection of water in drought-resistant varieties such as F 172 [1]. Proline accumulation could serve as a drought resistance measure [12]. Mexican sugarcane of the drought-tolerant cultivar My 54129 showed a greater decrease in nitrate reductase activity under drought than the susceptible variety My 5514 [8]. Stress resistance was similarly linked to abscisic acid accumulation [10]. The unsaturated fatty acid index was greater in drought-tolerant cultivars [19].

2.2. Water Logging Stress

One of the biggest risks to crops is flooding, which can affect crop production and lower yields by up to 100% depending on the intensity and length of the flood. Flood-related agricultural damage is also influenced by the crop's height and age. When a crop is tall enough and floods come, the crop sustains comparatively less damage than smaller crops. When choosing a water logging-tolerant variety, it may be preferable to have a fast-growing variety. Varieties of sugarcane with bobbin-shaped internodes are linked to their ability to withstand water logging. Plants under flooding stress experience serious physiological disturbances, including wilting, abscission, leaf loss and decay, epinasty and the production of lenticels. Flood damage causes nutrient loss and metal deposition on agricultural land, which results in nutritional deficiencies and metal phytotoxicity for any crop. Iron (Fe) toxicity is high in anaerobic conditions, which raises polyphenol oxidase activity and produces oxidized polyphenols. Additionally, water logging results in less root oxidation and leaf bronzing. Compared to flood-susceptible sugarcane cultivars, flood-tolerant sugarcane has a higher phosphorus level in the stalk. In water logging conditions, the nitrate reductase activity in flood-tolerant types decreases more slowly than in susceptible varieties, which fall more quickly. Compared to flood-susceptible kinds, flood-tolerant varieties exhibited higher levels of polyphenol oxidase activity in the root months [2].

2.3. Stress Due to Salinity

The presence of excessive amounts of soluble salts in the soil that interfere with or prevent a plant's normal growth and function is known as salinity stress. Electrical conductivity is used to measure it (ECE). Salinity is a type of physiologically dry environment where plants cannot absorb large amounts of water, which disrupts the plant's physiological and metabolic processes. In arid and semiarid parts of the planet, where there is not enough rainfall to remove the soluble salts from the root zone, salinity is a significant issue.

The osmotic or water deficit impact of salinity is the result of salt stress, which slows down plant growth by decreasing the plants' capacity to absorb water. Soluble salts in the plant's root zone interfere with the intake of water and the use of vital minerals like calcium. Saline soil is caused by calcium chloride, sodium carbonate, and sodium chloride. Stunted plant development, impacted seed germination, decreased crop production, and toxicity to plant cells due to altered enzyme function are all consequences of the increased buildup of Na+ and Cl-ions.

Changes in metabolic pathways, water stress, ion toxicity, nutritional problems, oxidative stress, decreased cell division, expansion, genotoxicity, and membrane disarray are some of the ways that salinity stress impacts plants. Regardless of their sucrose level, sugarcane crop cultivars with higher fiber content are more resilient to salt stress than those with lower fiber content. Chloride uptake and buildup in the leaf lamina can be inhibited by sugarcane cultivars [17]. Alkalinity tolerance in sugarcane can be assessed morphologically using waxiness and pink pigmentation [6].

2.4. Heat Stress

One of the main abiotic stressors that limit plant productivity is thought to be temperature. The degree of temperature rises, their duration, and the type of plant all affect how plants react to heat stress. Plant growth is negatively impacted by both high and low temperatures. Plants may be exposed to high temperatures every day or only sometimes. Based on their ability to withstand low, medium, or high temperatures, Plants into three groups: thermophiles, mesophiles, and psychrophiles [13]. Alterations in photosynthesis, decreased plant growth, pollen generation, seedling establishment, spilkelet sterility, grain and fruit development, crop quality, and yield are all consequences of high temperatures. Among the main harms brought on by high temperatures are protein denaturation, enzyme inactivation, reactive oxygen species generation, and membrane structure disturbance. Plants react to high temperatures by changing their metabolism. To guard against the high temperature stress tolerance, a variety of vital biomolecules are controlled, including hormones, metabolites, osmo-protectants, signaling molecules, polyamines, and antioxidants.

2.5. Low Temperature Stress

Low temperatures harm plants by freezing them down, which also causes anomalies in their development and physiology. Plants suffer direct or indirect cellular damage from low temperatures, such as freezing. Low temperatures can affect physiological processes, such rice blossoming. Common visual signs of low temperature stress include browning, wilting, damage to the leaves, bleaching from photooxidation of pigments, water plugging of the intercellular spaces, necrosis of the leaves, and plant death. [13]. Low temperatures lead to freezing and chilling, which harms crops. In addition to having a direct impact on crop growth and development, low temperatures can physically harm crops by interfering with their physiological and biochemical processes, which lowers agricultural output. Plants may be exposed to low temperatures on a daily or seasonal basis.

2.6. Air Pollution Stress

The surface of plants is constantly in contact with different air contaminants. Plants undergo various morphological and physiological changes when exposed to pollution. Pollutants harm the plant's trichomes, cuticle, and stomatal guard cells, which alters foliar morphology and causes additional harm to the plant. Plant leaves grown in polluted areas showed a striking variation in stomatal pore size, guard cell rupture, and cuticle and epicuticular wax degradation, according to scanning electron microscopy studies. The fundamental physiological process that is impacted by plants being directly exposed to air pollution is photosynthesis. High atmospheric concentrations of nitrogen oxides, ozone, and sulfur dioxide cause stomatal closure, which reduces the amount of carbon dioxide available for photosynthesis. Even seemingly insignificant alterations in stomata brought on by air pollutants can have a significant impact on a plant's ability to survive stress. The water balance of the leaf or entire plant may be further disrupted by these impacts. Plant photosynthetic ability is limited by stomata closure, reduced leaf area, and damage to the photosynthetic system. Through changes in thylakoid structure and function, reactive oxygen species (ROS) produced during oxidative stress harm photosynthetic machinery. The main mechanisms that adversely affect plants' photosynthetic efficiency include chlorophyll biosynthesis, RuBisco's carboxylation efficiency, and photosynthetic electron transport. When plants are exposed to air pollution, their respiratory systems are also impacted. Plants from heavily polluted areas exhibit significant anatomical changes; assimilatory tissues have higher concentrations of tannin or polyphenolic compounds; calcium oxalate crystals are more common; and the transfusion parenchyma exhibits the most changes [9]. It is anticipated that fluctuating asymmetry (FA) will rise as stress levels rise.

2.7. Wind-related Stress

Plant growth, development, and reproductive yield can be significantly impacted by wind, one of the most common environmental stresses [3-5]. By lowering leaf boundary layers and lowering plant temperature through transpiration cooling, wind frequently exacerbates water stress. The degree and frequency of stress, as well as the structure of the plant, determine how adaptable the plant is to such fluctuating external forces. Certain plant species respond to wind stress by thickening their stems and strengthening their tissues. However, in response to wind stress, other plant species exhibit an avoidance strategy by decreasing the thickness of their stems or petioles and their flexural rigidity. Since small plants encounter lower drag forces, these various tactics may be related to plant size and structure. Wind was shown to increase the vascular percentage in the petiole cross-section in the investigation of leaf petiole anatomy, indicating that greater water transport was necessary under wind stress [18].

2.8. Heavy Metals Stress

To combat the harmful effects of heavy metal stress, plants have a number of defense mechanisms. Secondary defense mechanisms include the binding of heavy metal ions by phytochelatins, glutathione, and amino acids, as well as the modification of antioxidant defense systems. Primary defense mechanisms include the decreased absorption of heavy metal ions or their sequestration in root cells. [11].

2.9. Ultraviolet Radiation Stress

Due to their immobility, plants are extremely vulnerable to UV-B light. Cell membranes and all internal organelles, such as the mitochondria, chloroplasts, and DNA in the nucleus, are harmed by UV-B radiation in plants. Basic plant metabolic functions like photosynthesis, growth, respiration, reproduction, and water management are all impacted, either directly or indirectly, by damage to these cell organelles. Increases in various UV-absorbing phenolics are the most typical reaction of field-grown plants to elevated UV-B levels. Crop quality and productivity are impacted by UV exposure. However, the impact of UV-B radiation varies depending on the stage of plant development, irradiation duration, and intensity. Furthermore, different plant species and cultivars of the same species have quite different levels of susceptibility to UV-B radiation. The species and the ratio of possible harm to the induction of defense and repair mechanisms determine the adverse consequences. Plants create the vibrant, water-soluble flavonoid pigments known as anthocyanins to shield their foliage from the harmful effects of UV light. Many plants' vibrant colors are caused by anthocyanins, which are found in large concentrations in fall foliage of deciduous plants as well as in flowers and fruits.

3. Biotic Stresses

When organisms interact, biotic stressors are created. Competition between species for resources leads to biotic stress. Allelopathic substances generated by one organism can also cause it to develop through parasitism and predation by preventing the growth of the other organism. Another type of biotic stress is disease. Bacteria, fungi, viruses, and nematodes are examples of biotic agents that cause disease. Cell walls, bark, and waxy epidermal cuticles are examples of barriers that serve as defense mechanisms. Waxy cuticles on the outside of plants offer antibacterial properties that keep disease-causing organisms out. For any creature that managed to get past the first barrier, the plant's cell wall serves as a second barrier. Even if an invader manages to get past the first and second barriers, they still need to beat the plant's immune system.

3.1. Disease Stress

Plants have evolved a multilayer surveillance system that allows them to recognize and detect pathogens and react quickly before they harm the plant. These plant monitoring systems are connected to particular defense reactions that have been preprogrammed. The first line of defense that shields plants from infections is innate immunity. Another name for innate immunity is basal resistance. When plant cells identify micro-associated molecular patterns (MAMPs), such as certain proteins, lipopolysaccharides, and cell wall components that are frequently present in microorganisms, basal resistance is triggered. Because these molecular components are widely distributed in plant cells, both pathogens and non-pathogens can cause basal resistance in plants. In order to reduce the basal resistance in some plant species, pathogens have evolved specific countermeasures. Plants may react with a hypersensitive response (HR), which is an additional line of defense, if a disease has the ability to suppress basal defense. Deliberate plant cell suicide at the infection site to preserve the entire plant is a hallmark of the hypersensitive response. Compared to baseline resistance, the hypersensitive response is more pathogen-specific. When gene products in the plant cell identify the presence of particular disease-causing chemicals that the pathogen has brought into the host, a hypersensitive reaction is frequently set off.

Systemic acquired resistance (SAR) is the term used to describe the long-term development of plant tissues' high resistance to a variety of pathogens following the initiation of the hypersensitive response. Chemicals known as plant activators are sprayed on plants to create artificially triggered SAR. A complex genetic defense process known as RNA silencing is one of the ways that plants can protect themselves from viruses. When some viruses replicate in a host cell, they create double-stranded DNA or RNA. In response to these foreign chemicals, plants may identify them, break down the genetic strands into ineffective pieces, and halt the infection. Virus-infected plants frequently show mottling and chlorosis, but if RNA silencing is successful, the disease signs may gradually go away; this is known as recovery. Certain chemicals are produced by plants in reaction to stress or microbial attack. Lignin is a highly branching, heterogeneous polymer that is present in plant secondary cell walls. Wood's main ingredient, lignin, is made up of hundreds of phenolic monomers. Because lignin is hard, insoluble, and nearly indigestible, it offers a strong physical defense against pathogen attack. When a pathogen attacks, phytoalexins isoflavonoids with antifungal and antibacterial properties are created. The pathogen's cellular structure and metabolism are disrupted by these poisonous chemicals, which include camalexin from Arabidopsis thaliana, rishitin from the Solanaceae family, and medicarpin from alfalfa. Some plants respond to pathogen attacks by producing hydrolytic enzymes. These hydrolytic enzymes build up in the extracellular spaces and break down the pathogenic fungus' cell walls. Chitin, which is found in fungal cell walls, is broken down by hydrolytic enzymes like chitinase. The breakdown of glycosidic bonds in glucans found in fungal cell walls is catalyzed by the enzyme glucanase. Increased resistance to a variety of diseases is exhibited by transgenic plants that express high quantities of these antifungal enzymes. Hydrolytic enzymes called lysozymes have the ability to break down bacterial cell walls.

3.2. Insect-pest Stress

Plants have sophisticated monitoring systems that can identify damage caused by insect pests and react with particular defense mechanisms. The presence of elicitors in chewing insect saliva allows plants to distinguish between general damage and insect eating. Additionally, plants release volatile organic compounds (VOCs) such sesquiterpenoids, homoterpenoids, and monoterpenoids in reaction to it. These substances may deter dangerous insects or draw in helpful predators that feed on the damaging vermin. For instance, when spider mites injure apple trees and Lima beans, they release volatiles that draw predatory mites. These substances can be produced systemically in intact plant tissues by feeding on a particular portion of the plant. Once released, these chemicals can serve as signals to nearby plants to start making similar compounds to stop the harm.

Plants create secondary compounds called phenols to protect themselves from infections. They contain a broad range of defense-related substances such flavonoids, lignin, tannins, anthocyanins, phytoalexins, and furanocoumarins and are synthesized in plants through the malonic and shikimic acid pathways. Many different types of plants create furanocoumarins, which are phenolic chemicals, in reaction to pathogen attack. Because of their incorporation into DNA, which speeds up cell death, they can be extremely poisonous to some vertebrate and invertebrate herbivores and are activated by ultraviolet light. Plants produce tannins, which are water-soluble flavonoid polymers that are kept in vacuoles. Because tannins bind to digestive enzymes like trypsin and chymotrypsin as well as salivary proteins, they inactivate the proteins, making them poisonous to insects. High tannin intake prevents insect herbivores from gaining weight and may even cause their death. Trypsin and chymotrypsin are two digestive enzymes that are inhibited by protease inhibitors, which are created in reaction to herbivore attacks. Numerous vascular plants contain nitrogenous substances called alkaloids, which include nicotine, cocaine, morphine, and caffeine. Many of these compounds have strong impacts on animal physiology and are generated from the amino acids aspartate, lysine, tyrosine, and tryptophan. Coffee, tea, and cocoa are examples of plants that contain caffeine, an alkaloid. Both fungus and insects are poisoned by it. Allelopathy is the term for the phenomena whereby coffee seedlings' high caffeine levels prevent other seeds from germinating around the developing plants.

Tobacco plants create the alkaloid nicotine in their roots, which is then carried to the leaves and stored in vacuoles. When herbivores nibble on the leaves and crack open the vacuoles, it is released. The deadly nightshade plant produces atropine, a neurotoxic and heart stimulant. Nitrogenous substances known as cyanogenic glycosides decompose to form hydrogen cyanide (HCN), a deadly substance that stops aerobic organisms' cells from respiring. Enzymes like glycosidases and hydroxynitrile lyases are also produced by plants that produce cyanogenic glycosides, but they are kept in other parts of the plant or tissues. When insects consume plant tissues, the substrates and enzymes combine to form deadly hydrogen cyanide. Herbivore induced plant volatiles (HIPVs): Depending on the insect and plant species, plants release a variety of volatile and non-volatile chemicals to protect themselves from insect feeding. In reaction to insect attacks, plants release HIPVs lipophilic chemicals with a greater vapour pressure into the atmosphere from their leaves, flowers, and fruits as well as into the soil from their roots. Different defense signaling pathways are triggered for the generation of particular volatile chemicals based on the methods that insect pests feed [20].

4. Conclusion

An overview of how biotic and abiotic stressors impact plant productivity and production is given in this article. Climate is the most crucial element in optimizing the potential of any crop, regardless of location. Climate change has an impact on crop productivity, which is a significant obstacle to food security. Agricultural productivity is greatly impacted by weather events and the use of germplasm, which scientists must continuously improve and replace to make it resistant to various biotic and abiotic challenges. Researchers strive to understand the pathway associated with stress reactions in order to generate data that could be utilized in breeding programs. The comprehensive application of all biotic and abiotic stress adaption techniques ensures a sustainable, high-quality output and productivity. Future research will, in general, focus on determining practical biotic and abiotic stress adaptation strategies that smallholder farmers might employ.

Abbreviations

FA	Fluctuating Asymmetry
HIPV	Herbivore Induced Plant Volatiles
ECE	Electrical Conductivity

Author Contributions

Meseret Degefa Regassa is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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